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[PROC. ROY SOC VICTORIA, 55 (N.S.), PT. I., 1943.]

# ART I.—*Fixation of Phosphate in Some Victorian Soils.*

By MARY R. LAWRY, B.Agr Sc.

[School of Agriculture, Melbourne University ]

[Read 9th April, 1942; issued separately 1st May, 1943.]

## Abstract.

Red soils on basalt in Gippsland give greater growth of pasture with lime and superphosphate than with superphosphate alone, on account of fixing phosphate in an unavailable adsorbed form. Various chemical extractions are recorded for these and for other soils which respond normally to superphosphate The ratio f adsorbed to adsorbable phosphate is much lower for the high-fixing an for normal soils

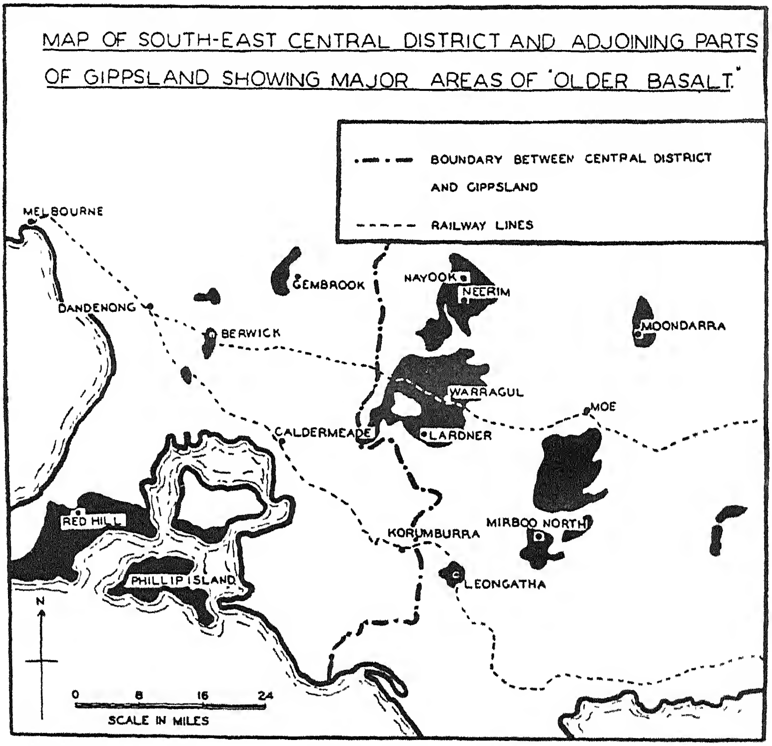
Most Victorian soils show evidence of phosphate deficiency which can be remedied by the application of superphosphate. An isolated group of deep red loams on oligocene basalt in South Gippsland near Mirboo North (see map), have shown a greater growth of pasture with lime and superphosphate, than with superphosphate alone; lime alone has little effect. This suggests that part of the added phosphate is being fixed by the soil in a form not available for plants, and that the addition of lime increases the availability of this phosphate. The term " fixation " has long been used to describe the conversion of soluble phosphate, added to the soil, into forms insoluble in water. In this paper the term is restricted to include only the conversion into forms not available for plants.

Soils occur in many parts of the world which fix soluble phosphate so firmly that plants can obtain little benefit from the application of superphosphate. These soils include both acidic and alkaline types; the present paper is concerned with acidic types only. The Hawaiian soils formed from basalt are the most widely quoted example of this problem. In Australia the most striking example is found on the basaltic country around Lismore, on the north coast of New South Wales. The climate of both these areas is warm and wet. The soils are friable and permeable, though high in clay; they are high in sesquioxides and red is the predominating colour. These are extreme cases in which added superphosphate has no effect at all. This conversion of phosphate into unavailable forms is slight in the red basaltic soils of South Gippsland, and is shown only by the additional response to lime and superphosphate mentioned above. Presumably the lime acts by reducing the activity of aluminium and iron compounds.

The literature on this subject is voluminous. In acid soils fixation in an unavailable form has been attributed to two constituents, free ferric oxide and kaolinite, which hold phosphate as an anion on their surfaces. Usually importance is attached

to the role of free ferric oxide in phosphate fixation, but Burd and Murphy (1) hold that kaolinite is mainly responsible, on account of the activity of the surface layer of alumina in its crystals.

The discussion of the problem by Burd and Murphy is particularly useful and is summarized and commented on in the following paragraphs. The analytical work reported here is a repetition of their methods, which were devised in order to estimate the phosphate status of the soils and to predict any future deficiencies. They chose 14 widely differing Californian soils, and obtained a good correlation between experimental results and field experience.




*Absorbed Phosphate.*

Burd and Murphy extract the soil with 0·1 N NaOH and thus determine the "adsorbed phosphate" by replacement with hydroxide. Dickman and Bray (2) suggest the use of neutral fluoride as a replacing ion since it does not dissolve organic matter. However, the small amount of organic phosphorus dissolved by alkali does not seriously increase the estimate of adsorbed phosphate.

The capacity of the soil to adsorb phosphate was next estimated by shaking a sample of soil with a solution of $KH_2PO_4$, filtering and washing, and again determining the phosphate extracted by alkali. This figure is called the "adsorption capacity." The ratio of adsorbed phosphate to adsorption capacity, expressed as a percentage, is called the "degree of saturation." The higher this degree, the less firmly held and therefore the more available will any added phosphate be.

Burd and Murphy consider that it is useful to compare the "adsorption deficit"—that is, the difference between the two NaOH extractions—with the total phosphate. Thus Aiken clay, (see Table 1), which shows the most acute deficiency of their samples, has a far greater adsorption deficit than it has total phosphate. On the other hand, Yolo silty clay loam, which shows no phosphate deficiency, has a total supply of phosphate far above its adsorption deficit.

Unless the degree of saturation is high, adsorbed phosphate can only be available to plants by anionic exchange between the root hair surface and the soil particles. An extracting solution containing an anion of high replacing power should only be used for determining adsorbed phosphate, not for estimating available phosphate.

*Dilute Acid Extracts.*

The traditional line of attack is extraction with dilute acid. This can only give an approximate picture of the conditions existing between the plant and the soil. The plant obtains its phosphate by solution from soil particles due to an increase in acidity of the soil solution around the root. The best an acid extraction can do is to try to reproduce the simple acidity effects in the neighbourhood of the root hairs. Extraction with citric acid cannot do this since it also releases adsorbed phosphate. Phosphate adsorbed on the positive parts of soil colloids can be displaced by citrate ion, and although some plants may excrete organic anions which are strongly adsorbed, in general plants cannot use adsorbed phosphate unless the individual soil particles are themselves fairly well saturated with phosphate. Burd and Murphy describe the choice of citric acid as a solvent as "perhaps the most unfortunate occurrence in the history of soil phosphate investigation."

Hydrochloric acid comes close to the ideal since chloride ion has low displacing power. Burd and Murphy used 0·01 N HCl. The solution of sulphuric acid and ammonium sulphate recommended by Truog (12) is as high as M/40 in sulphate ion. It would therefore be expected to dissolve adsorbed phosphate more vigorously than dilute hydrochloric acid. Russell and Prescott (10, p. 89) found that sulphuric acid alone dissolved three times as much phosphate as did hydrochloric acid of the same normality.

*Field Evidence in Victoria.*

Most of the evidence of the phosphate status of the Victorian soils here described is given by experiments conducted by the Victorian Pasture Improvement League (V.P.I.L.) which has established numerous plots in southern districts to determine the best treatments with fertilizer. These plots are mowed periodically and the clippings weighed.

The superphosphate is applied annually at the rate of 2 cwt. per acre; (some plots receive an additional 1 cwt.); lime was only applied at the beginning of the experiments at the rate of 1 ton of calcium hydroxide per acre. This took place in 1935 for Lardner and Mirboo, and in 1932 for Korumburra, Caldermeade and Pakenham.

Superphosphate causes greater growth throughout the growing season of August to January. Any additional growth caused by lime is only obtained at the first spring cut in September (15, p. 216).

## Description of Soils.

The soils tested are described below. They are referred to throughout this paper by their place names.

*Red Soils.*

Samples were taken from three sets of V.P.I.L. plots on the red soil formed on basalt near Mirboo North, in the hills of South Gippsland. The profiles of these are similar, viz. dark reddish brown friable clay loam at the surface, passing gradually to red friable clay at a depth of a foot. The soils are remarkably permeable in spite of the high proportion of clay. Solid rock is not usually found within several feet of the surface, but there may be occasional "floaters." The original vegetation was a heavy Eucalyptus forest, and particles of charcoal and baked clay are found in the surface soil, being residues of forest fires. The average annual rainfall is 45 inches.

*Mirboo I.* From Mr. Bickerton's property at Limonite. Application of lime caused a 50 per cent. increase over superphosphate alone in each of the years 1936-9. Organic carbon 4·1 per cent., pH 5·4.

*Mirboo II.* From Mr. Austin's property, Mirboo North. Lime caused 30 per cent. increase over superphosphate alone in the years 1936-7, and about 20 per cent. thereafter. Organic carbon 2·8 per cent., pH 5·8.

*Mirboo III.* From Messrs. Edney, Mirboo North. Lime caused no increase over superphosphate alone in 1936, then 30 per cent. increase each year 1937-39. Organic carbon 4·1 per cent., pH 5·8.

Samples were taken from two other places on the basalt near and north of Warragul.

*Lardner* (rainfall 40 inches) from V.P.I.L. plots on Mr. Teese's property. This soil is on the edge of the basalt and differs strikingly from the Mirboo soils. It is greyish brown with ironstone concretions from the surface downwards. It is deficient in potassium and has given no additional growth with lime. Organic carbon 3·8 per cent., pH 5·4.

*Nayook* (rainfall 48 inches). This soil is under Eucalyptus forest. The profile is essentially similar to the Mirboo samples. Organic carbon 4·2 per cent., pH 5·5.

A further sample was included from the Lismore district, New South Wales, since this type has been intensively studied by Holman (5) and Parbery (8).

*Wollongbar* (rainfall 52 inches). Red friable clay loam, overlying red friable clay, with weathered basalt at about 5 feet. No response to lime has been established here. The fixing power for phosphate is very high. Organic carbon 3·4 per cent., pH 4·0.

*Grey and Black Soils.*

A sample developed on Oligocene basalt was taken from Berwick (Vic.), where both reddish-brown and black soils are formed on this same parent material.

*Berwick* (rainfall 34 inches). Black friable clay overlying greyish black heavy clay, with decomposing rock at 2 feet (6, p. 192). Subsoil much less permeable than the red types. No evidence of added growth with lime. Organic carbon 4·2 per cent., pH 5·6.

The remaining samples are taken from other V.P.I.L. plots. They show no response to lime, but are included for interest as they lie near the red soils of Mirboo under a similar climate.

*Korumburra* (rainfall 46 inches). The surface soil is a grey clay loam with a yellowish grey clay at 12 inches, which passes into decomposing rock which is a felspathic sandstone of Jurassic age. This is an immature podzolic type. Organic carbon 2·9 per cent., pH 5·3.

*Caldermeade* (rainfall 30 inches). Dark grey clay loam, passing into heavy clay at 8 inches. The land is flat and low-lying and has been described as "swamp fringe" type by Goudie (3). Organic carbon 4·2 per cent., pH 5·0.

*Pakenham* (rainfall 34 inches). Light grey sandy loam, overlying yellow sandy clay at 18 inches. This is a well-marked podzol similar to Harkaway sand (6, p. 187). Organic carbon 2·5 per cent., pH 5·5.

The mean annual temperature for the Victorian stations is close to 57°F.; rainfall reaches a maximum in winter and early spring. At Wollongbar the mean annual temperature is 67°F.; the rain falls mainly in summer and autumn.

All the surface soils in the Victorian samples are from 0–3 inches, subsurface from 3–12 inches. The surface sample from Wollongbar is from 0–9 inches.

The two Californian soils already referred to have been thus described (16).

*Aiken clay* is a somewhat lateritic soil developed on basalt in rolling country. The surface is a dull red clay which passes gradually into the subsoil which is a more pronounced red, compact and with a heavier texture, being high in clay. Both soil and subsoil are mildly acidic in reaction and contain aggregates or concretions cemented by sesquioxides of iron and manganese and with accumulated phosphate in an insoluble and unavailable form.

*Yolo silty clay loam* is a deep immature light coloured alluvial soil, alkaline in reaction, rich in lime and mineral plant nutrients, but low in organic matter.

## Analytical Methods.

### *Phosphate in Adsorbed Condition.*

Thirty gram of soil was shaken for 1 hour with 150 c.cs. 0·1 N NaOH. The suspension was centrifuged and the supernatant liquid was poured off, diluted with an equal volume of 0·1 N NaOH, and filtered through a porcelain candle. An aliquot of 20 c.cs. of the black filtrate was boiled with 15 c.cs. concentrated sulphuric acid in a Kjeldahl flask, adding 5 gm. $Na_2SO_4.10H_2O$ and 1 gm. $MnSO_4$ crystals as catalyst. The colourless product was diluted, filtered from silica, and made up to 100 c.cs. with distilled water. An aliquot of 5 or 10 c.cs. was neutralized with ammonia using $\alpha$-dinitrophenol as indicator, and the phosphate determined colorimetrically.

### *Adsorption Capacity.*

Thirty gram of soil was shaken for 15 hours with 150 c.cs. of $KH_2PO_4$ solution containing 3 mg. $PO_4$ per cc. The soil was filtered and washed with distilled water until 1500 c.cs. had passed through. It was then shaken with 150 c.cs. 0·1 N NaOH, and treated in the same way as the previous soda extract. When determining the adsorption capacity of soils after the removal of free ferric oxide (see below), the suspension after extraction with soda was flocculated with sodium sulphate, instead of being filtered through the candle.

This method yields a lower figure for adsorbed phosphate than would be given by the alternative method of simply determining the phosphate left in the solution of $KH_2PO_4$ after coming to equilibrium with the soil. The difference between the two methods is not very serious. Burd and Murphy say that they leached out "free phosphate" in the soil with distilled water. However,

even after prolonged washing the soil still yields some phosphate to distilled water and the above method has been used in order to remove the most lightly held fraction.

*Acid-soluble Phosphate.*

Thirty gram soil was shaken intermittently with 150 c.cs. ·01 N HCl for 24 hours. The temperature of the suspensions was kept close to 20°C. during the day.

Before the phosphate in the extract could be determined colorimetrically, organic matter and ferric iron had to be destroyed. The extract was evaporated to dryness and treated successively with 1 c.c. concentrated hydrochloric acid containing a drop of nitric acid and hydrogen peroxide prepared by mixing sodium peroxide and sulphuric acid. The residue was left to stand overnight with an acid solution of sodium sulphite to destroy ferric iron. The phosphate was then determined colorimetrically.

*Colorimetric Determination of Phosphate.*

The method used (reduction of phosphomolybdate) was based on that given by Truog and Meyer (14). The aliquot was neutralized in a 50 c.c. standard flask with ammonia, using $\alpha$-dinitrophenol as indicator. The volume was made up to about 40 c.cs., 2 c.cs. molybdate solution added (a 2·5 per cent. ammonium molybdate solution in $10N\text{–}H_2SO_4$); then 5 c.cs. diluted stannous chloride solution, and the volume made to 50 c.cs. The blue colour was compared with the standard after 10 minutes.

A 3·75 per cent. solution of hydrated stannous chloride in N HCl was stored under paraffin and diluted with water (1 : 10) as required.

The sodium hydroxide and ammonia solutions were stored in waxed bottles to avoid contamination by silicate which also forms a blue compound under these conditions.

*Phosphate Soluble in Concentrated Hydrochloric Acid.*

The soil was boiled for 2 hrs. with concentrated hydrochloric acid, and the phosphate determined gravimetrically as phosphomolybdate.

*Free Ferric Oxide.*

This was found using the method of Truog et al (13) viz. extraction with $Na_2S$ at pH 7 followed by acidification with oxalic acid.

*Organic Carbon.*

This was determined by the approximate volumetric method of Tiurin (11).

## Discussion of Results.

*Dilute Acid Extracts.*

The amounts extracted by dilute acid (Table I. col. 6) are very low compared with the American figures except that for Aiken clay, which appears to be of the same order as the red soils from Mirboo. Plots of the red soils which have been annually topdressed with 2 cwt. per acre of superphosphate for the last five years give similarly low figures, whether treated with lime or not. The uncultivated forest soil from Nayook gives a strikingly low figure.

Table I.—Phosphate Status of Various Surface Soils.

All Australian samples are 0–3 inches except Wollongbar, 0–9 inches.

| Locality or Soil Type. | $PO_4$ per 100 gm. Soil. | | Present Degree of Saturation. | $PO_4$ per 100 gm Soil | | $PO_4$ Soluble in ·01 N HCl. | Field Evidence of Phosphate Status. |
|---|---|---|---|---|---|---|---|
| | Adsorption Capacity. | In Adsorbed Condition. | | Adsorption Deficit. | Dissolved by Conc. HCl. | | |
| | mg. | mg. | % | mg. | mg | p.p m | |
| Mirboo I. .. | 173 | 26 | 15 | 147 | 116 | 1·2 | 20–50 per cent. increase with superphosphate. Lime + superphosphate, 50 per cent. above superphosphate alone |
| Mirboo II. .. | 161 | 18 | 11 | 143 | 72 | 0·7 | Over 50 per cent. increase with superphosphate. Lime + superphosphate, small additional increase |
| Mirboo III. | 192 | 16 | 8 | 176 | 100 | 1·0 | 100–200 per cent. increase with superphosphate. Lime + superphosphate, 30 per cent. above superphosphate alone |
| Nayook .. | 246 | 3 | 1 | 243 | 56 | 0·1 | Forest |
| Lardner .. | 173 | 11 | 6 | 162 | 122 | 0·7 | 50 per cent. increase with superphosphate only after adding potassium |
| Wollongbar | 308 | 19 | 6 | 289 | 920 | 1·3 | Pasture not improved by phosphate with or without lime. Symptoms of deficiency observed. |
| Korumburra | 165 | 60 | 36 | 105 | 108 | 1·2 | Nearly 100 per cent. increase with superphosphate. No improvement with lime. |
| Caldermeade | 106 | 47 | 45 | 59 | 130 | 5·6 | 50-100 per cent. increase with superphosphate. No improvement with lime |
| Pakenham .. | 90 | 26 | 39 | 64 | 48 | 1·7 | Big increase with superphosphate |
| Berwick .. | 52 | 15 | 29 | 37 | 64 | 2·3 | Increased growth with superphosphate |
| Aiken clay | 547 | 22 | 4 | 525 | 160* | 2·0† | Extreme phosphate deficiency |
| Yolo silty clay loam | 55 | 27 | 48 | 28 | 200* | 91 | No phosphate deficiency |

* Fusion analyses.

† Burd and Murphy give this figure as 0·2 mgm. per cent (p. 335). It is probably a misprint for <0·2. Murphy on page 351 of the same issue records all acid extracts of Aiken clay as being <0·2 though he apparently did not determine the actual amount present.

When working with a soil from Lismore similar to Wollongbar, Holman (5) found that over the pH range of 8 to 2 both native and added phosphate were completely insoluble.

The grey soils of Korumburra and Caldermeade, after ten years of topdressing with 3 cwt. superphosphate per acre, show increases in extractable phosphate; viz. from 1·2 to 4·0 and from 5·6 to 7·5 parts per million respectively. The black soil at Berwick developed on the same parent material as the red Gippsland soils has a higher figure for soluble phosphate.

The pH values of the acid extracts of the unlimed samples were either within or close to the range 4·0–4·5; the limed plots gave extracts 0·5–1 pH unit above the unlimed.

Table 2 shows that the sub-surface horizons contain much less phosphate in the adsorbed condition or dissolved in dilute acid. This would be expected, and confirms the general opinion that the top few inches of soil are the most important.

TABLE 2—PHOSPHATE STATUS OF SUBSURFACE HORIZONS (3–12 INCHES).

| Locality. | In Adsorbed Condition | Extracted by ·01 N. HCl. |
|---|---|---|
| | mg. $PO_4$ per 100 gm soil | p.p.m. $PO_4$ |
| Mirboo I. | 5 | 0·1 |
| Mirboo II. | 8 | 0·3 |
| Mirboo III | 8 | 0·4 |
| Nayook | 0·1 | 0·1 |
| Korumburra | 13 | 0·5 |
| Caldermeade | 14 | 0·2 |

*Adsorbed Phosphate.*

Dealing next with adsorbed phosphate, the most important feature of Table 1 is the figure for percentage saturation, which shows a good correlation with experience in the field. This figure is high for the grey or black soils (Korumburra, Caldermeade, Berwick, Pakenham) which respond normally to superphosphate; and for Yolo silty clay loam, which naturally yields an ample supply of phosphate to plants. It is low for the red soils. Of these, the soils of Mirboo are recorded as giving additional response to superphosphate when lime is added. Lardner gives no such response to lime. An acute deficiency in potassium has been found there, and this may be a complicating factor.

Aiken clay is very deficient in phosphate, but Burd and Murphy give no indication of the effect of applied superphosphate or lime.

The soil from Wollongbar is peculiar. It is very high in total phosphate, but has a low percentage saturation, and yields little phosphate to dilute acids or in the Neubauer test (8) The pastures, consisting mainly of Paspalum, give no indication of response to superphosphate with or without lime. This soil may be similar to Hawaiian soils quoted by Heck (4) where the fixing power is so intense that liming to pH 6·5, which he calls the point of maximum solubility of the phosphate, causes only a slight improvement.

*Free Ferric Oxide.*

Free ferric oxide (Table 3), while lower in the red soils of Gippsland than in the Wollongbar sample, is higher than in the neighbouring grey soils such as Caldermeade. In the black sample from Berwick, however, it is actually higher than in the red soils of Mirboo.

TABLE 3.—FREE FERRIC OXIDE AND ITS EFFECT ON ADSORPTION CAPACITY

| Locality. | Free Ferric Oxide. | Adsorption Capacity $PO_4$ per 100 gm Soil. Before Removing $Fe_2O_3$. | Adsorption Capacity $PO_4$ per 100 gm Soil. After Removing $Fe_2O_3$. |
|---|---|---|---|
| | % | mgm | mgm |
| Mirboo I. .. | 4·9 | 173 | 13 |
| Nayook . . .. | 3·2 | 246 | 13 |
| Lardner . .. . .. | 2·9 | 173 | 7 |
| Wollongbar .. . .. | 11·2 | 308 | 22 |
| Korumburra .. . . | 2·7 | 165 | n.d. |
| Caldermeade . . . | 1·0 | 106 | n.d. |
| Pakenham .. . | 1·7 | 90 | n.d. |
| Berwick .. .. .. .. | 5·2 | 52 | n.d. |

The adsorption capacity of the soils after the removal of free ferric oxide is very low. It must be concluded that in the soils studied, the greater part of phosphate fixation takes place on the surface of free ferric oxide.

*Silica-sesquioxide Ratio.*

Any study of the fundamental nature of the problem of phosphate fixation should include a knowledge of both the chemical composition and physical structure of the colloid in the soils taken. This has not been attempted, but the following figures for silica-sesquioxide ratios of similar soils are of interest. Prescott and Hosking (9) give a $\frac{SiO_2}{R_2O_3}$ ratio of 0·7 for their sample from Wollongbar; this was much the lowest ratio of all the red basaltic soils from Queensland and New South Wales

which they studied. A common figure for this group of soils was 1·4. Red soils on basalt near Berwick have a ratio of 1·7 (6, p. 234). It is likely that the red Mirboo and Nayook soils are similar.

*Staining Tests.*

Lundblad (7) has suggested an approximate method of finding the colloidal properties of soils, by measuring the amounts of methylene blue and alizarin R which the soil can adsorb. The amount of each dye adsorbed depends on the amount and nature of colloidal matter in the soil. The cation of methylene blue is adsorbed onto the negative part of the colloid (silicate or humate) and the anion of alizarin R onto the sesquioxides. The ratio of $\frac{\text{cation adsorbed}}{\text{anion adsorbed}}$ thus gives a measure of the silica-sesquioxide ratio.

Table 4 shows the results obtained following Lundblad's method using alizarin S instead of alizarin R.

TABLE 4—CAPACITY OF SOILS TO ADSORB METHYLENE BLUE AND ALIZARIN S.

| Locality | Methylene Blue Adsorbed by 1 gm. Soil | Alizarin S Adsorbed by 1 gm Soil. | Relative Adsorbing Power $\frac{\text{Col. 1}}{\text{Col. 2}}$ |
|---|---|---|---|
| | mg. | mg | |
| Mirboo I. | 52 | 15 | 3·5 |
| Lardner | 42 | 17 | 2·5 |
| Wollongbar | 20 | 17 | 1·2 |
| Korumburra | 38 | 12 | 3·2 |
| Caldermeade | 66 | 8 | 8·2 |
| Pakenham | 22 | 4 | 5·5 |
| Berwick | 80 | 16 | 5·0 |

The siliceous soils of Caldermeade, Berwick and Pakenham have high ratios. Wollongbar, as expected, is low, Mirboo, Lardner and Korumburra intermediate. Soils with a relatively low ratio and a high capacity for adsorbing alizarin S, would be expected also to have a high adsorption capacity for phosphate. This does not mean that all these soils have a high fixing capacity for phosphate, as they already may be fairly saturated, e.g. Korumburra. The low ratio for Korumburra can be correlated with its high ferric oxide content.

## CONCLUSION.

In conclusion, it appears that the analytical methods suggested by Burd and Murphy will be useful in diagnosing the state of phosphate in the field; and as more figures are obtained, their usefulness should increase.

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ART. II.—*Studies in the Physiology of Host-Parasite Relations.*

# III. FACTORS AFFECTING RESISTANCE TO BACTERIAL WILT OF SOLANACEAE.

By B. J. GRIEVE,

Botany School, University of Melbourne.

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## Abstract.

Studies on invasion of potato and tomato plants by *Bacterium solanacearum* show that high soil moisture, temperatures over 66°F., light intensity over 800 ft. candles, and high humidity favour the disease under glasshouse conditions. A correlation was made with the conditions obtaining in the field in Victoria. The rate of movement of the parasite in the vessels was 5·0 mm. per hour for potato and 2·2 mm. per hour for tomato at 73°F. The minimum, optimum and maximum temperatures for growth of *B. solanacearum* were 15°C., 32°C. and 35°C. respectively.

Significant increases in height, vessel size and in water content developed in plants grown in wet soil conditions. The increased water content is believed to be the factor which influences the susceptibility of the plant to invasion. Results of growth experiments showed a positive relation between spread of disease and vigour of growth in the host.


## Introduction.

The literature on Bacterial Wilt of Solanaceae caused by *Bacterium solanacearum* E.F.S. (*Phytomonas solanaceara* Bergey *et al.*) includes references indicating that resistance or susceptibility of plants to invasion is related to such external factors as soil moisture, temperature and humidity and to such internal factors as "sappiness" of plants. Smith (1914, 1920) in the United States of America commented on the fact that turgid, rapidly growing tomato plants were more susceptible to the disease, and Van der Meer (1929) working on Slime Disease of Tobacco in Sumatra demonstrated that plants growing in wet soil were more rapidly invaded than those in drier soil.

In no case however, has any attempt been made to analyse the resistance or susceptibility of the plant under varying environmental conditions in terms of the growth physiology of the host and of the parasite. In the present paper the approach to the problem has been made from this angle. The effect of soil

moisture, temperature, light and humidity on invasion has been studied under partially controlled conditions. A study has also been made of the growth of healthy plants under similar environmental conditions in order to see if there was any relation between vigour of growth in the host and parasitism by *Bacterium solanacearum*. The growth of the parasite in culture media at different temperatures has also been investigated so that the information might be related to invasion at different temperatures in the host.

## Materials and Methods.

Methods of inoculation and histological techniques were as described in an earlier paper (Grieve, 1940).

The majority of the experiments were carried out in a glass-house at Melbourne University; some in pots in the open and others in a compartment with constant light, temperature and humidity at the Botany School, Cambridge.

For the experiments both potato (var Carman) and tomato plants (var. Marglobe) were used. The latter proved more suitable and were used in greater numbers. As many of the experiments involved comparisons between plants subjected to different environmental conditions, a method had to be adopted to ensure that the plants were as closely similar as possible at the start of the experiment. The principle of the "paired plant" method of Bolas and Melville (1933) was accordingly adopted for the work. Plants from one sowing were grown to a selected leaf stage and then graded into pairs or threes of equal size and vigour. Factors such as height, leaf area and stem thickness were taken into account in pairing.

When two sets of conditions were being compared, two groups of plants were made, the individuals of any pair being in opposite groups. Members of one series then continued growth under the original set of environmental conditions while their opposite numbers were subjected to the changed conditions. Or again both series continued their growth under changed conditions In the experiments dealing with the effect of soil moisture on invasion, tomato and potato plants in sets of threes were grown to the selected leaf stage under identical conditions of soil watering and then some days before inoculation, heavy watering of one series was commenced and continued for the duration of the experiment (Wet Soil Series). Members of the second

series received the normal amount of watering (Normally Watered Series), while members of the third series received only sufficient water daily to keep them turgid (Dry Soil Series) The water in the dry soil series varied from 6 to 8 per cent. of the moisture free soil in different experiments; in the normally watered soil from 18 to 20 per cent., while in the wet soil series it varied from 29 to 31 per cent. In some experiments the disease was allowed to run its course, observations being made on occurrence of symptoms in each series. In other experiments sample plants were taken at intervals from each series and the degree of invasion established by infection testing and sectioning For the experiments dealing with the effect of light on invasion, plants were grouped in threes of equal size and vigour; one set of plants was exposed to normal light in the glasshouse (this was heavily whitewashed in summer so that the maximum values rarely rose above 1,000 foot candles (ft. c.) and the average during the experiments was 800 ft. c.), the second and third sets were shaded by calico to give decreased light intensities of 400 and 130 ft. c. respectively. Pots were so arranged in the glasshouse bench as to expose the plants to approximately the same environmental conditions. In the humidity testing experiments, members of one group were placed under glass cabinets, while their opposite numbers remained exposed on the glasshouse bench. The same procedure of pairing plants was followed for the experiments on growth and water content of healthy plants held under different soil moisture conditions. Samples of ten plants from each set of conditions were taken at the start, and after convenient time intervals until the conclusion of the experiment, the means were then determined. For dry weights the plants were left in an oven at 100°C. for 24 hours. Light intensity was measured at three hourly intervals using a Weston Light Meter and a mean determined, while average temperature was computed from a thermograph record. The probability of the results being due to chance were calculated according to Fisher's modification of "Student's Method".

## Experimental Results.

### Part I.—The Effect of Certain Partially Controlled Environmental Conditions on Resistance to Bacterial Wilt.

#### Soil Moisture.

The results of glasshouse experiments involving observations on 102 potato plants and 60 tomato plants ranging in development from the fifth to the eighth expanded leaf stage are summarized in Table 1.

TABLE I.—THE EFFECT OF SOIL MOISTURE ON BACTERIAL INVASION.
(Temperature 69°F.–75°F.; Light Intensity, 600–800 ft. c.)

| — | Dry Soil | Normal Soil. | Wet Soil. |
|---|---|---|---|
| Potato—Days for wilting . | 21·6 | 10·7 | 9·2 |
| Mean diff. with S.E. . | 10·9 ± 0·73 | | 1·5 ± 0·36 |
| Value of P. . | <0·01 | | <0·01 |
| Tomato—Days for wilting . | 23·4 | 11·6 | 7·6 |
| Mean diff. with S.E. . | 11·8 ± 0·97 | | 4·0 ± 0·50 |
| Value of P. . .. | <0·01 | | <0·01 |

The results of these studies show that plants growing in dry soil are significantly more resistant to spread of the bacterial wilt organism in the tissues than those grown in normally watered soil, while plants growing in wet soil are very susceptible. Only 60 per cent. of the total plants inoculated under dry soil conditions developed wilting symptoms whereas all inoculated plants in wet soil wilted.

In the field, infection very commonly occurs from the soil through damaged roots, so experiments were made to test the effect of soil moisture on invasion using tomato plants in which lateral roots were slightly damaged. It was found that eighteen to twenty-five days elapsed before wilting developed in plants growing in soil moist conditions and forty days and above before it developed in plants in dry soil. Very frequently infection failed to occur in the latter group of plants.

The period elapsing between exposure of damaged roots to the possibility of infection and actual invasion, under either set of conditions could not be accurately determined, but fifteen to twenty days elapsed before bacteria could be seen in the tap root. Root invaded plants wilted much more rapidly and completely once the bacteria entered the main root system than did plants which were needle prick inoculated. This is due to the fact that invasion of all stem bundles commonly occurs in the root infected plants with consequent early interference with the transpiration stream.

The name "Sore Eye" disease of tubers describes a condition where there is a mattery bacterial exudate from the eyes of infected tubers and particles of moist soil cling around them. This condition in the field is peculiar to soils in which the soil

moisture content is high as in the Koo-wee-rup area in Victoria. The "Sore Eye" appearance was produced experimentally in tubers of stem-inoculated potato plants growing in the open in large pots in which the soil moisture was kept high. The condition did not develop in similar soil with a lower water content. The "Sore Eye" condition is due to intense proliferation of the bacteria in the tuber bundles leading to destruction of the eye tissues with consequent bacterial exudate.

The above results show clearly that high soil moisture favours heavy and rapid bacterial invasion, while in dry soil, plants are more resistant to the spread of the organism in the tissues. As the disease occurs most seriously in the moist soil of the Koo-wee-rup area in Victoria, the results indicate a positive relation between soil moisture and the incidence of the disease in the field.

### Air Temperature and Light.

Experiments dealing with the effect of air temperatures were carried out in a glasshouse during the years 1937, 1940 and 1941. No facilities were available for the control of temperature, so, to test the effect of different temperature levels the experiments were done during different seasons, i.e., summer and early and late autumn. Light intensity was decreased during the experiment in summer and early autumn by the use of calico shades over batches of experimental plants. Plants at the same leaf stage in the different seasons were selected. Results are presented in Table II. The broad effect of light was tested during summer months at an average temperature of 73°F. in the glasshouse, results being given in Table III.

Table II.—Effect of Air Temperature on Invasion in Tomato.
(Three replications of 5 plants inoculated at the five-leaf stage.)

| | | | | |
|---|---|---|---|---|
| Mean air temperature . . . | 73°F. | 66°F. | 59°F. | 50°F. |
| Mean light Intensity in ft. candles . | 400 | 400 | 400 | 200 |
| Days for wilting . . . . | 5·4 | 5·9 | 24·3 | No infection |
| Mean difference with S.E . | (0·5 ± 0·4) | | (18·4 ± 1·03) | |
| Value of P. . . . . . | 0·3—0·2 | | <0·01 | |

Two experiments at a constant temperature of 77°F. were carried out at the Botany School, Cambridge, in a controlled environment compartment. Half the plants (total number = 12

in each experiment)·were given 1,000 ft. c. continuous lighting and the other half 500 ft. c. continuous lighting. Results are included under Table III.

The criteria of successful invasion by the parasite were epinasty and wilting and the times of occurrence of these were recorded. Sections also were cut at different levels to assess the relative numbers of the organisms present in the vessels.

TABLE III.—EFFECT OF LIGHT ON INVASION IN TOMATO.

(Three replications of 5 plants inoculated at the five-leaf stage.)

| | | | |
|---|---|---|---|
| Mean light intensity in ft. candles | 800 | 400 | 130 |
| Mean air temperature | 73°F. | 73°F. | 73°F |
| Days for wilting | 4·1 | 4·8 | 7·0 |
| Mean difference with S.E. | (0·7 ± 0·3) | | (2·2 ± 0·97) |
| Value of P | 0·05–0·04 | | 0·05–0·04 |

EXPERIMENTS IN A CONTROLLED COMPARTMENT.

| | | |
|---|---|---|
| Light intensity in ft. candles | 1000 (continuous) | 500 (continuous) |
| Air temperature (constant) | 77°F. (continuous) | 77°F. (continuous) |
| Days for wilting | 2 | 2 |

Table II. shows that invasion at 73°F. and 66°F. was significantly more rapid than at 59°F. No significant difference was found between the times of wilting for the two higher temperatures. At 50°F. the plants were still growing slowly but no symptoms developed after inoculation. Sections showed that the bacteria had failed to multiply.

From Table III. it may be seen that reduction of light by half significantly affected the time of appearance of wilting in the glasshouse experiments, but there was no difference in the case of the controlled compartment experiments. With reduction to one-sixth the normal light value, epinasty developed before wilting and the incubation period for wilting was significantly longer. It may be noted that the incubation periods given in Tables II. and III. are shorter than those in Table I. This occurs because plants used in the soil moisture experiments were somewhat older being at the 7th expanded leaf stage at the time

of inoculation. The above results indicate that both temperature and light strongly influence invasion rate as indicated by time of appearance of symptoms.

ATMOSPHERIC HUMIDITY.

A comparison was made between the degree of invasion in tomato plants grown on a glasshouse bench at an average temperature of 73°F. where the relative humidity varied but averaged approximately 55 per cent. and others grown at the same temperature but enclosed in glass cabinets. Owing to the absence of wilting symptoms in plants kept under highly humid conditions the criteria of invasion used were relative numbers of bacteria in the vessels, and the rate of movement up and down the bundles. It was found that exposure to the high humidity consistently increased susceptibility as shown by a greater multiplication of the bacteria in the vessels leading to their breaking out of the xylem into other tissues The rate of movement of the bacteria in the vessels under both sets of conditions was however approximately the same. The experiments also served to show that the spread of the bacteria in the vessels is largely independent of transpiration rate since water loss from the plants under highly humid conditions is negligible.

RATE OF MOVEMENT OF THE PARASITE IN THE VESSELS.

In the earlier stages of invasion up to incipient wilting, the bacteria are largely confined to the vascular bundles (Grieve, 1939) and it is possible to determine the rate of progress of the parasite up and down invaded vessels. Experiments were performed at an average temperature in the glasshouse of 73°F. and under three sets of soil moisture conditions. The organism was inoculated into main stem bundles at a point 2 to 3 inches above soil level or alternatively a short distance below the apex of the plant. The distance moved by the bacteria was determined using a staining and sectioning method. Two corrections were applied. The first was for average vessel length. This was necessary because the organisms on inoculation are carried to various points up and down the length of the vessels punctured, under the influence of the negative pressure in the tracheae. The second correction was for the vessel incubation period. This is the time taken by the parasite to multiply to such a degree as to fill the vessels into which it was originally introduced before commencing to spread to others. This was found at 70–75°F. to be approximately 24 hours in the case of plants growing in normally moist soil, 18 to 20 hours in wet soil and variable periods up to 72 hours and over for plants in dry soil. Results are given in Table IV.

TABLE IV.—MEAN RATES OF MOVEMENT OF BACTERIA IN VESSELS IN MMS. PER HOUR.

(Mean Temperature 73°F.)

| Host. | Direction of Movement | Dry Soil. | Normal Soil. | Wet Soil. |
|---|---|---|---|---|
| Tomato .. | Up .. . | 0·3 | 0·8 | 1·1 |
| | Down . .. | 0·3 | 1·0 | 1·1 |
| | Total . . | 0·6 | 1 8 | 2·2 |
| | Mean diff. and S.E. | 1·2 ± 0·3 (Dry–Normal) | 0·4 ± 0·17 (Normal–Wet) | |
| | Value of P. .. | 0·01 (Dry–Normal) | 0·1–0·05 (Normal–Wet) | |
| Potato .. | Up .. | .. | 2·3 | 3·7 Mean diff. and S.E. 2·4 ± 0·2 P. <0·01 (Up–Down) |
| | Down .. .. | .. | 1.3 | 1·3 |
| | Total .. .. | .. | 3.6 | 5·0 |
| | Mean diff and S.E. | .. | 1·4 ± 0·27 (Normal–Wet) | |
| | Value of P. .. | .. | <0·01 (Normal–Wet) | |

It is to be observed that the rate of movement in potato plants is greater than in that of tomato and that this rate is greatest in wet soil. Comparing the rates of upward and downward movement in each plant group, the evidence is that in potato the bacteria move upward in the xylem more rapidly whereas in tomato there is no significant difference between the rates under each set of soil conditions. An interesting result was obtained when tomato and potato plants were inoculated in bundles near the top of the stem. The bacteria grew back very rapidly in the vessels, rates as high as 4·0–5·0 mms. per hour being obtained in potato under normal soil moisture conditions. The interest in determining the rates of upward and downward movement lay in connection with suggestions by earlier investigators that transpiration was an important factor in the upward movement. These results together with those in the preceding section do not favour such a view.

## VESSEL DIMENSIONS IN POTATO AND TOMATO PLANTS.

It will be seen from Table IV. that the rate of movement of the bacteria in the vessels of potato plants is consistently higher than in tomato plants when both are of similar age and growing under the same environmental conditions. It appeared therefore, that internal factors peculiar to each plant were operative in producing the differential speeds of vessel invasion observed. Among such factors would be (*a*) length and diameter of vessels, (*b*) food content in vessels.

The second of these does not allow of satisfactory determination with present techniques. It seems reasonable to suppose however that there would be certain differences in metabolites present in the vessels of the two plants and that these would react on bacterial growth.

Length of vessels was determined using the mercury method and mean diameters estimated from camera lucida drawings. Results are given in Table V. In fig. 1, a comparison is given of the relative stem cross-sectional areas and of the diameters of vessels of potato and tomato plants (both at the 7 expanded leaf stage) cut two inches above soil level.

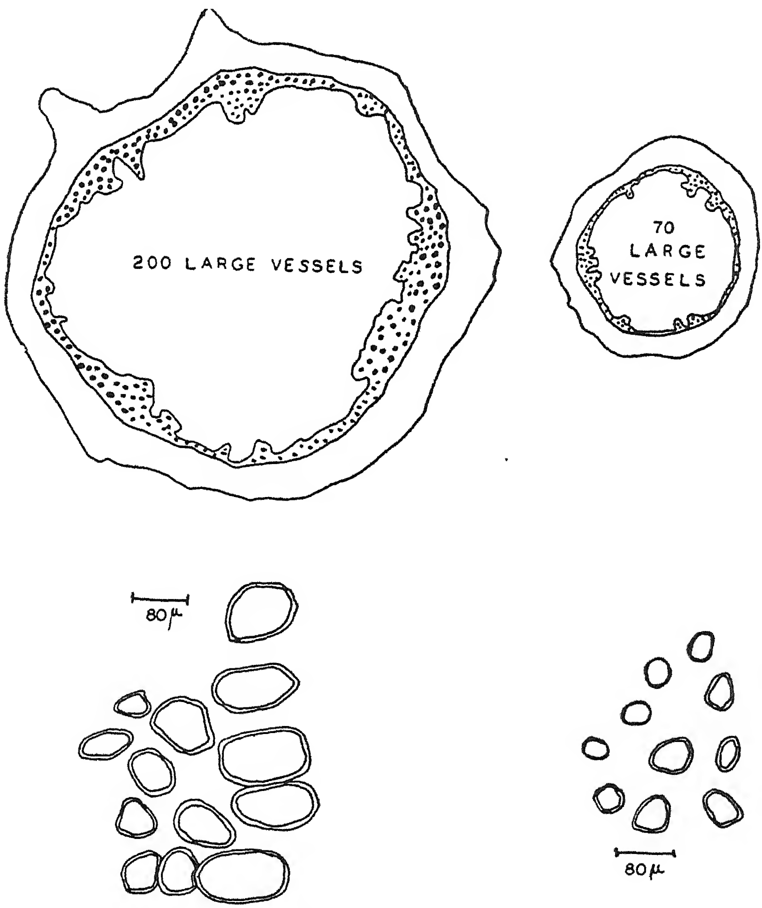


FIG. 1.—Comparison of relative cross-sectional areas and of diameters of vessels of potato and tomato plants at the 7 expanded leaf stage.

TABLE V.—VESSEL DIMENSIONS IN TOMATO AND POTATO PLANTS AT THE 5TH–6TH LEAF STAGE.

| — | Mean Diameter Near Stem Base. | Length in Cms. |
|---|---|---|
| Tomato .. .. .. .. | 63 x 60 $\mu$ | 5·0 ± 2·1 |
| Potato .. .. | 108 x 96 $\mu$ | 6·5 ± 2 0 |

Reference to Table V. shows that vessel diameters in potato are rather greater than in tomato and it is possible that this difference in size *per se.* is related to the more rapid spread of the organism in the former. It is conceivable also that the larger vessels might contain more metabolites which sustain the growth of the bacteria.

GROWTH OF BACTERIUM SOLANACEARUM AT DIFFERENT TEMPERATURES.

To determine the minimum, optimum and maximum temperatures for growth of the pathogen, experiments were carried out in solid media. Needle point transfers were made on plates, poured with beef extract agar at pH 6·7, so that eight equi-distant colonies were grown in each petri dish. Two dishes were grown at each of the temperatures shown in fig. 2. The diameters of the colonies were measured after six days and averaged, and this mean diameter was taken as the measure of growth. The optimum temperature for growth over a six-day period is seen to occur (fig. 2) at 32°C. after which there is a very sharp fall when the temperature is raised to 35°C. When

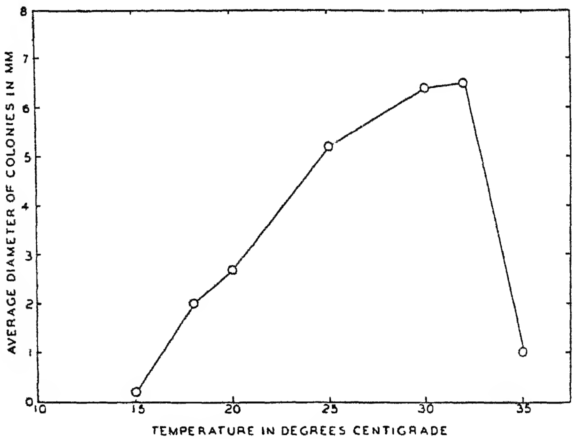


FIG 2.—The effect of temperature on the development of *B. solanacearum* as measured by average colony diameters on nutrient agar (pH 6.7) after six days' incubation.

the time of incubation of the plates was increased beyond six days, growth in size of the colonies at 30°C and 32°C proceeded much more slowly and this reduction in growth rate was associated with the production of a deep brown to black pigment. Colony growth at 20°C. and 25°C. continued normally up to 14 days so that colonies at 20°C during this time came to approximately the same size as those at 30°C. Colonies at the lower temperatures (20°–25°C) showed no brown pigment formation, but on transfer to the 30°C incubator, pigment developed within three days.

COMPARISON WITH OTHER INVESTIGATORS.

Van der Meer (1929) working in Sumatra with a strain of *Bacterium solanacearum* E.F.S. causing Slime Disease of Tobacco, found a positive relation between high soil moisture and rapidity of wilting of infected plants. The present results for "Sore Eye" potato disease in Victoria conform with her findings in regard to soil moisture.

From data in Table I. of Van der Meer's paper, the rates of movement of bacteria in tomato plants grown under "dry" and "wet" soil conditions have been calculated and are shown in Table VI. A period of 24 hours was assumed to apply for vessel incubation period. The climatic conditions were probably such as to favour rapid invasion although Van der Meer makes no mention of temperature or of light values. Table VI. also includes a comparison of Van der Meer's results with those of the author. The values for "wet" soil plants agree fairly closely. The differences in the case of "dry" soil plants is probably due to the fact that the moisture content of the soil in Van der Meer's experiments was lower than that of the soil used by the author.

TABLE VI.—RATE OF MOVEMENT OF BACTERIA IN TOMATO STEMS IN MMS. PER HOUR

| Authority | Upwards. | | Downwards. | |
|---|---|---|---|---|
| | Dry Soil. | Wet Soil | Dry Soil. | Wet Soil |
| Van der Meer . . .. | 0·0 | 1·0 | 0·0 | 1·0 |
| Grieve .. . . | 0·3 | 1·1 | 0·3 | 1·1 |

Both sets of data show that rate of movement is very much greater in the plants growing under conditions of high soil moisture. Estimation of rates of movement in potato plants from data obtained by Smith (1914) in U.S.A., gave values ranging from 0·9–1·7 mm. per hour which are considerably lower than those obtained by the author.

Vong (1937) has calculated the rate of movement of *B. solanacearum* in tobacco plants. He found that it was greater in the downward direction being the order of 0·2692 mm. per hour as against 0·2586 mm. per hour upwards at 25°C. (77°F.) and 24 hours after inoculation. Vong's calculation of the rate to four significant figures suggests a very high degree of uniformity of plant material in relation to invasion. Such uniformity does not occur in potato and tomato plants used in the author's experiments.

The minimum, optimum and maximum temperatures for migration of *B. solanacearum* according to Vong (1937) are 15°C., 32°C., and 40°C. respectively. The author's results are in agreement with the first two values, but the maximum for growth in the Victorian strain was found to be 35°C.

Smith, in the United States of America (1914), reported that the minimum for growth was 10°C., the optimum 35°–37°C. and the maximum 41°C. Eddins (1936) reported a minimum temperature of 55°F. (12·8°C.) for the development of the disease in the field in Florida (U S.A.). It appears therefore that the temperature relations of the organism vary in different parts of the world.

Van der Meer (1929) was of the opinion that increased susceptibility to invasion of plants grown under conditions of high soil moisture was due to increased "sappiness" of the plants. This view had also been sponsored earlier by Smith (1914, 1920). In neither case, however, was any fundamental research undertaken on the relation between "sappiness" and susceptibility.

## Part II.—Effect of Certain Partially Controlled Environmental Conditions on the Growth of Healthy Tomato Plants.

### Soil Moisture.

In the course of the experiments on the rate of invasion in tomato plants under various soil conditions, it was observed that those plants growing in wet soil appeared to show greater growth in height and leaf area as well as greater "sappiness" than those grown under drier soil conditions. It appeared likely that these differences bore some relation to the increased susceptibility of the plant, so experiments to obtain quantitative data were commenced. In three experiments, batches of 50 to 60 tomato plants growing under the same soil conditions were first graded into pairs as described earlier. Determinations for dry weights and water content apply to stem parts from the cotyledon scars upwards. The variability between members of a pair at the beginning of an experiment was found to be small. Members

of one group were next watered heavily to produce soil moist conditions (soil moisture varying from 29–31 per cent. of moisture free soil in separate experiments), and the plants of the sister group watered lightly to give dry soil conditions (soil moisture varying from 6 to 8 per cent. of moisture free soil in different experiments). Treatment was continued for periods varying from 5 to 21 days when a further sample of ten plants from the soil moist group with their opposite numbers from the dry soil group was made. Results of representative experiments for the attributes of water content and height are given in Tables VII. and VIII. Mean values at the first and second samplings for ten plants of each group in two experiments are plotted in figs. 3 and 4.

TABLE VII.—EFFECT OF SOIL MOISTURE ON WATER CONTENT IN TOMATO

(Experiment 3—22/5/'41 to 27/5/'41.—Sample after 5 days of exposure to wet and dry soil conditions.)

| Pair Number | Wet Soil. (W) | Dry Soil. (D). | Difference. (W–D) |
|---|---|---|---|
| 1 | 94·20 | 93·00 | 1·20 |
| 2 | 94·98 | 94·06 | 0·92 |
| 3 | 94·95 | 93·84 | 1·11 |
| 4 | 94·91 | 93·02 | 1·89 |
| 5 | 95·05 | 94·00 | 1·05 |
| 6 | 95·27 | 93·14 | 2·13 |
| 7 | 94·70 | 93·23 | 1·47 |
| 8 | 94·41 | 94·33 | 0·08 |
| 9 | 95·61 | 94·55 | 1·06 |
| 10 | 95·42 | 92·85 | 2·57 |
| Means | 94·950 | 93·602 | 1·348 (P. <0·01) |

TABLE VIII.—EFFECT OF SOIL MOISTURE ON GROWTH IN HEIGHT IN TOMATO

(Experiment 2.—16/3/'41 to 6/4/'41.—Sample after exposure of 21 days to wet soil and dry soil conditions.)

| Pair Number. | Wet Soil. (W). | Dry Soil. (D). | Difference. (W–D). |
|---|---|---|---|
| | cms. | cms. | cms. |
| 1 | 21·0 | 15·0 | 6·0 |
| 2 | 25·3 | 17·0 | 8·3 |
| 3 | 21·5 | 20·0 | 1·5 |
| 4 | 21·0 | 15·0 | 6·0 |
| 5 | 13·5 | 11·5 | 2·0 |
| 6 | 15·5 | 11·5 | 4·0 |
| 7 | 13·0 | 12·5 | 0·5 |
| 8 | 14·0 | 11·5 | 2·5 |
| 9 | 10·3 | 9·5 | 0·8 |
| 10 | 16·5 | 10·0 | 6·5 |
| Means | 17·16 | 13·35 | 3·81 (P. <0·01) |

The tables and figures show that significant differences occur in water content and in height between the wet soil and dry soil plants. The mean changes between the percentage water contents of the paired plants during the experiment tabled was 1·35 which is highly significant even with the small sample of ten plants. In the experiment dealing with the effect of soil moisture in growth in height, the mean change between the paired plants was 3·81 cms. which is again highly significant. In figs 3 and 4, the mean differences in height and in water content between samples of ten plants at the beginning and end of two experiments is given. A significant difference also was found to occur between leaf areas of plants grown in wet soil and dry soil, but no significant difference was found between the dry weights of plants grown under such conditions.

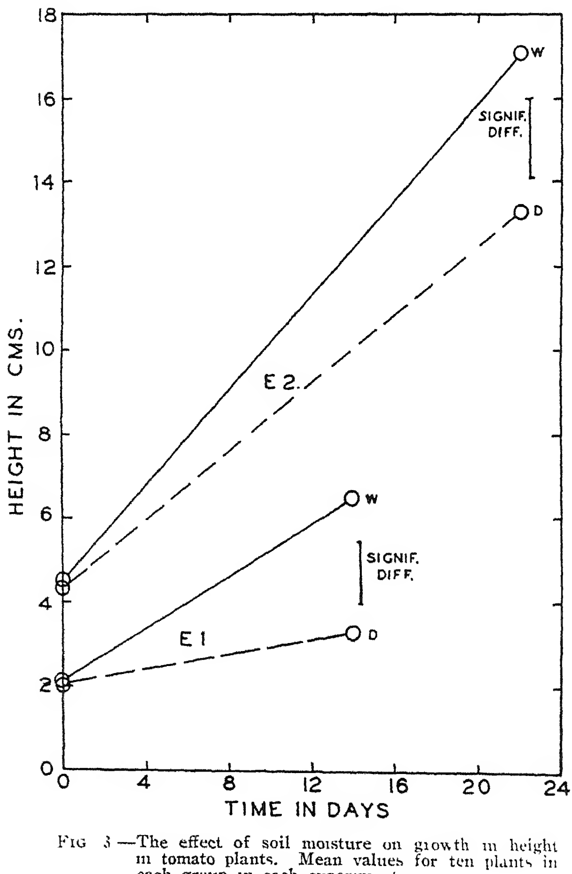


FIG 3.—The effect of soil moisture on growth in height in tomato plants. Mean values for ten plants in each group in each experiment.
W = wet soil, D = dry soil

Microscopical examination of sections cut at soil level and at the level of the third leaf from the apex, showed that the vessels in plants grown in wet soil were larger and more numerous than those in the plants from dry soil. With the aid of a microprojector and a planimeter the actual areas of the xylem were determined and were found to be consistently greater in plants from wet soil. Fig. 5 shows a typical example, in which the area of the xylem in the stem of the plant growing in wet soil is 3·5 sq. cms. as against 1·7 sq. cms. for the plant in the dry soil. The percentage areas of the xylem relative to the whole stem area in both were found to be approximately the same.

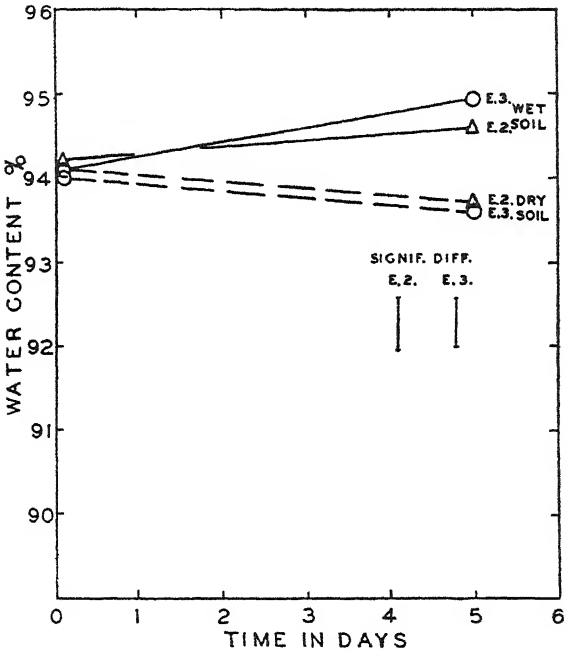


FIG. 4.—The effect of soil moisture on water content in tomato plants. Mean values for ten plants in each group in each experiment

These experiments show that important physiological and anatomical differences arise between tomato plants growing under wet soil conditions and those growing under dry soil conditions. The increased "sappiness" of the plants in wet soil, their increased height and the anatomical changes therein appear to be directly or indirectly the outcome of the significant increase in the water content in such plants. The relation of these

changes in the host to susceptibility to bacterial invasion will be discussed later.

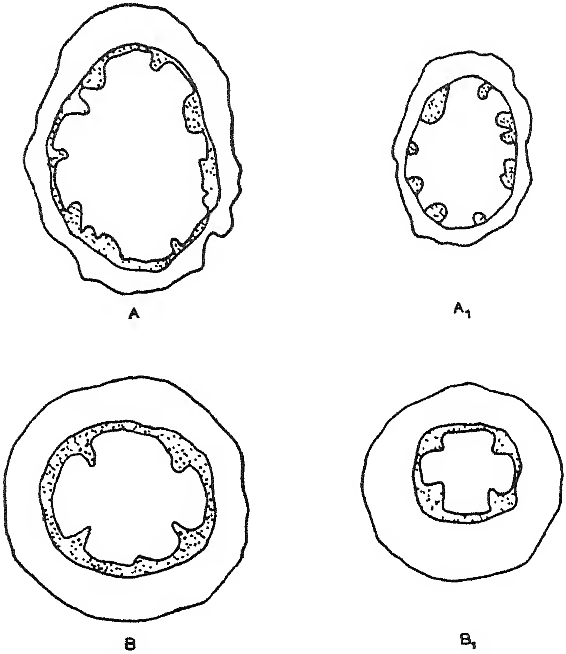


FIG 5.—Relative development of vascular tissue in tomato plants grown in wet soil (left) and dry soil
A, $A_1$ = stem: B, $B_1$ = root.

## AIR TEMPERATURES.

In the section dealing with the effect of temperature and of light on rapidity of invasion in tomato, it was shown that the most rapid spread of the parasite in the vessels (as judged by symptoms) occurred at an average temperature between 66°F. and 73°F. at an average light intensity of 800 ft c.

It was a matter of common observation that plants under these conditions appeared to be growing faster than those at the lower temperature levels where invasion was also slower. This suggested that the activity of the parasite was related to the vigour of growth in the host when soil moisture content was normal. A considerable body of data on the effect of temperature and light at different seasons of the year on the growth of tomato plants (var. E.S.I.) is available from the work of Ainsworth and Selman (1936), Bolas (1934), Bolas and Selman (1935), and Bolas, Melville and Selman (1938). This data could be used in relating vigour of growth of the plant to rapidity of invasion by the parasite, but it was decided that it would be of

value to obtain data for the growth of the tomato variety used (Marglobe) under the seasonal conditions obtaining in Melbourne. Accordingly five series of experiments were carried out at different seasons giving a range of temperature and light values. Plants with three to four expanded leaves were used in the different experiments (except for Expt. 1 in which plants were at the five leaf stage) during summer, autumn and spring, since it is preferable to use plants at the same stage of development rather than plants of the same age (Bolas, Melville and Selman (1938).

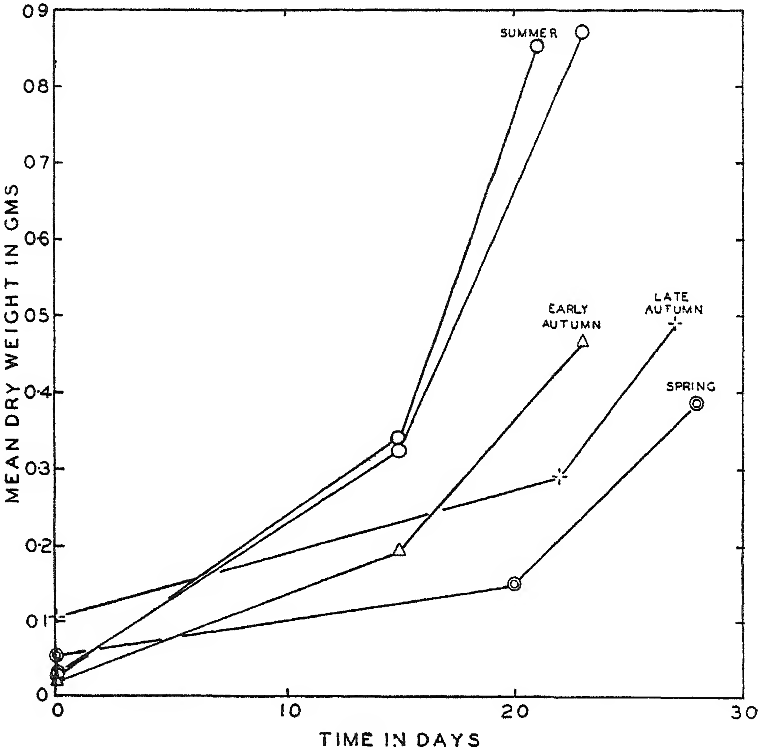


FIG. 6.—Dry weight growth curves for tomato plants at different seasons.

Results of experiments are summarized in Table IX. Fig 6 shows growth curves for the five series, mean dry weights of whole plants being plotted against time in days. Dry weights give the most comprehensive summary of growth but it was considered of value to examine another measure of growth, namely, height. Growth curves for height are shown in fig. 7. These curves show that growth during autumn and spring is lower than during summer with its higher temperature and light values.

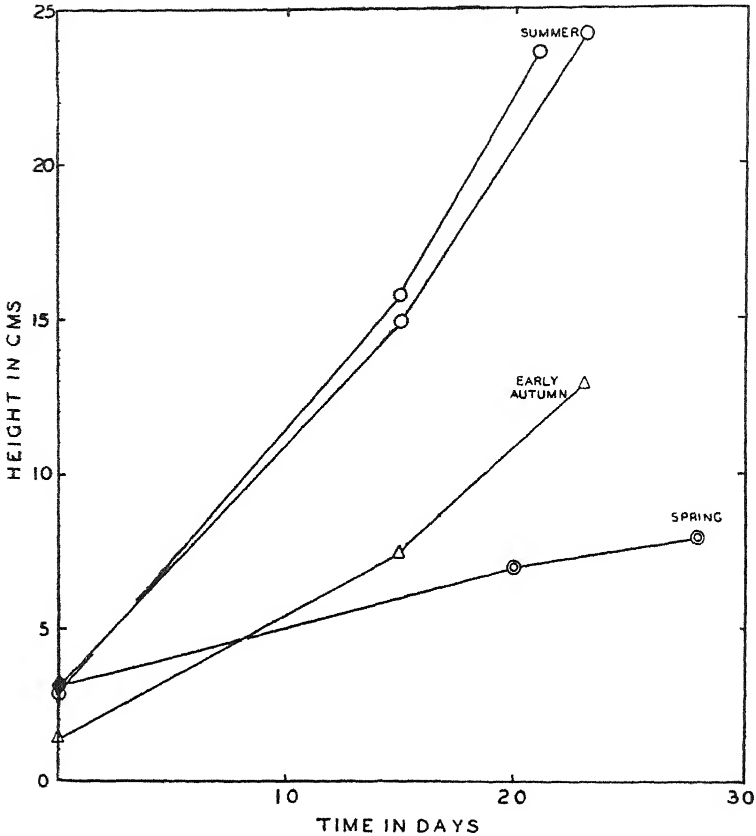


FIG. 7.—Growth curves for height in tomato plants grown at different seasons

When the logarithms of the dry weights were plotted against time the curves obtained approximated to straight lines and the slope of these curves was taken as a measure of the growth rate—

$$\text{Growth Rate} = \frac{\log \mathrm{Wt}_2 - \log \mathrm{Wt}_1}{t_2 - t_1}$$

where $Wt_1$ and $Wt_2$ are the dry weights of the whole plant at the beginning ($t_1$) and at the end ($t_2$) of the experiment. Growth rates plotted against time of year are shown in fig. 8. The higher growth rate for summer is associated with higher light and temperature values.

These results show general agreement with the more extensive data of Ainsworth and Selman (1936). Representative growth curves from the data of these workers are plotted in fig. 9 for comparison.

The relation between the growth of the host at different seasons and the growth and rapidity of invasion by the parasite *B solanacearum* is discussed in the following section.

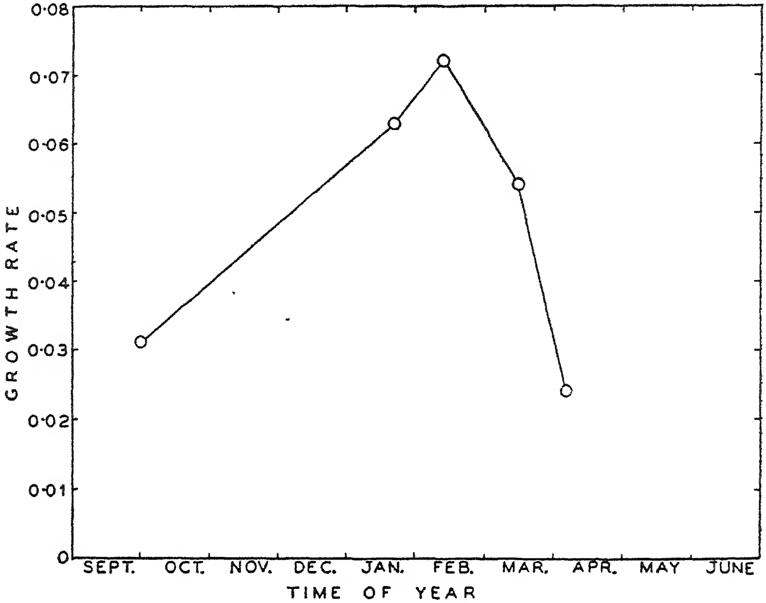


FIG 8.—Growth rates in tomato plants at different times of the year.

TABLE IX.—GROWTH OF TOMATO PLANTS AT DIFFERENT SEASONS.

| — | | Expt. 1 13·3·41 to 9·4·41 Av. Temp = 62°F. | Expt. 2 17·9·41 to 15·10·41 Av. Temp = 59°F. | Expt. 3 12·1·42 to 2·2·42 Av. Temp = 75°F. | Expt. 4 20·1·42 to 12·2·42 Av. Temp = 78°F. | Expt. 5 27·2·42 to 21·3·42 Av. Temp = 69°F. |
|---|---|---|---|---|---|---|
| Sample I. | Time in days | 0 | 0 | 0 | 0 | 0 |
| | Height in cms. | | 3·2 | 3·2 | 2·9 | 1·4 |
| | Dry wt. in gms. | 0·109 | 0·052 | 0·030 | 0·029 | 0·026 |
| Sample II. | Time in days | 22 | 20 | 15 | 15 | 15 |
| | Height in cms. | .. | 7·0 | 14·85 | 15·3 | 7·5 |
| | Dry wt. in gms. | 0·290 | 0·138 | 0·321 | 0·340 | 0·194 |
| Sample III. | Time in days | 27 | 28 | 23 | 21 | 23 |
| | Height in cms | .. | 7·9 | 24·15 | 23·7 | 12·8 |
| | Dry wt. in gms | 0·480 | 0·387 | 0·872 | 0·850 | 0·466 |

Dry weights and heights = means of ten plants.

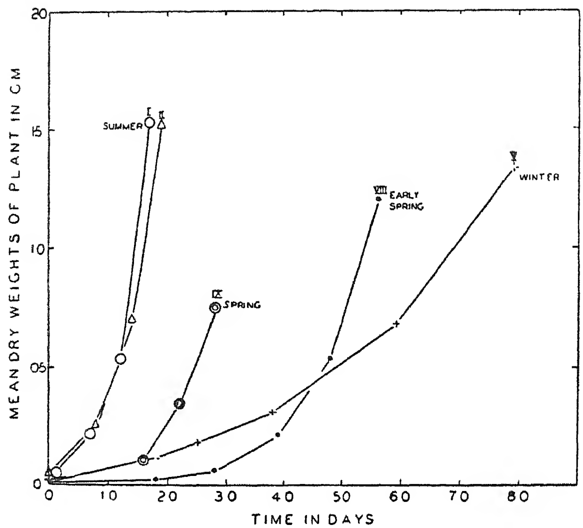


FIG. 9.—Growth curves for tomato seedlings Plotted from Ainsworth and Selman's data (1936)

## Discussion.

From the data presented it is apparent that under the conditions of these experiments there is a relation between maximum "invasiveness" and soil and air moisture, temperature and light intensity. The first three factors affect the physiology both of the host and of the parasite, while light affects the physiology of the host. In attempting a closer analysis of the relation between these factors and susceptibility to invasion, we may consider first how they affect those processes or conditions in the plant which might react favourably or unfavourably on the parasite.

### GROWTH RATE AND WATER CONTENT.

Under suitable conditions of light and temperature, high soil moisture has been shown to affect favourably the growth in height and leaf area of healthy tomato plants as compared with those grown in dry soil. No significant difference, however, was found between the dry weights of plants grown under wet soil and dry soil conditions. The water content of wet soil plants rose significantly higher than those of the dry soil series and it appears that it is this factor which affects in large measure certain aspects of the growth of plants.

Increase in size in the plant may be considered to be the result of cell division and cell enlargement. The importance of water

to these processes is obvious. Referring to the soil moisture experiments, it may be concluded that under dry soil conditions the relative deficiency of water exercised a depressant effect on cell growth which was reflected in the smaller height and leaf area of such plants. The comparative observations on the growth of healthy plants covered only those in wet and dry soils and no quantitative data on differences between the plants grown in normal soil-moisture and those of the two extremes is available. Rough comparisons made while other experiments were in progress indicated, however, that plants in wet soil were "sappier" than plants growing in normally watered soil.

The terms "sappiness" and "sappy" have been applied to certain glasshouse grown plants which, owing to the conditions of their culture, develop a relatively high water content and which consequently show certain well defined differences from the normal. Such plants are rather larger than normal, the leaves are thinner and of a paler green colour and there is a lack of anthocyanin pigment in the stem. The manner in which the increased water content acts on the plant to bring about these changes is not known. Miller (1929) and Shaw (1934) suggest in the case of "sappy" apple twigs that changed moisture conditions in the intercellular spaces may be concerned. This does not, however, appear to be in accordance with our knowledge of water relations in tissue development.

The finding that no significant increase in dry weight developed between the dry and wet soil series is interesting. In this connection Melville's work (1937) on the relation between water content and carbon assimilation in tomato (var. E.S.1) offers a likely explanation. He found that there was a marked rise in assimilation as the initial water content of whole plants increased from 89 to 91·5 per cent., but with values above 91·5 per cent. (in "long-night" plants) a rapid decline in assimilation set in. The condition of "long-night" plants approximates in some degree to that of plants from moist soil in so far as water content is concerned. Data on water content in the experiments here reported was taken only for stem and leaf parts and the values even for plants from dry soil were higher than Melville's figure of 89 per cent., but they would have been considerably reduced if the roots had been included. It is possible therefore that the same feature of depressed assimilation would occur. Thus any depression in assimilation in plants from dry soil due to water content below 90 per cent. would be compensated by a similar depression in assimilation in plants from wet soil when the water content reaches such a high level as to be pathological.

The changes in the host under wet soil conditions which appear to have the closest bearing on the growth of the parasite are (*a*) increase in water content, (*b*) increase in size of vessels. Increased water content leading to increased "sappiness" has a very definite effect upon the growth of the parasite. This effect, independent of possible complications due to increased transpiration, is shown in the massive multiplication of the organisms in vessels of plants held under highly humid conditions. Precisely how it acts upon the parasite is not clear Van der Meer (1929) performed experiments on the growth of *B. solanacearum* on moist and dry agar and concluded that high moisture gave most active growth of the pathogen. Similar experiments by the author with *B. solanacearum* and other bacterial plant pathogens demonstrated that they too gave better growth on moist agar. Walter (1925), moreover, demonstrated that high relative humidity is a general condition for successful growth of many micro-organisms. Van der Meer's view that because this particular parasite grew better on moist agar it therefore should grow better in the vessels of a "sappy" plant consequently seems open to question. It is difficult to understand why, if water *per se.* is important, the mere increase of it in the xylem vessels and parenchyma cells should affect the parasite so much in the case of prick inoculated plants. Earlier experiments (Grieve, 1940) showed that even in plants at the wilting stage the water columns in the tracheae remained continuous. It seems more likely that the more successful parasitism in wet soil plants may be due to greater availability of metabolites for bacterial nutrition made possible by the enhanced water supply. It is possible that, in some way not at present understood, reduced absorption of water in dry-soil plants affects deleteriously the absorption of mineral salts and the leakage of other food materials into the tracheae.

Brown (1936) discusses the question of water content in relation to parasitism and suggests (e.g. for *Bacillus carotovorus* Jones) that there is a relationship between water content and enzyme action by the parasite. In sub-turgid tissues the enzyme cannot operate. While the author has no evidence that enzyme action of the type evidenced by *B. carotovorus* exists in the case of *B. solanacearum*, the possibility of some such mechanism also being operative is not excluded.

It is of interest to note that a close relationship between high water content and susceptibility to invasion has been recorded in the case of several other diseases e.g. of pear to *B. amylovorus* (Shaw, 1934); of tobacco leaves to *B. angulatum* and *B. tabacum* (Clayton, 1935), and potato leaves to *Phytophthora infestans* (Napper, 1933).

Increased transpiration in moist soil conditions is associated with increased water content of tomato plants (Foster and Tatman, 1937), but there is no evidence in the experiments reported here, to suggest that this increased transpiration has any effect in speeding up invasion by carrying the bacteria upwards in the vessels. On the introduction of bacterial cells into the vessels by needle prick they are carried up and down to various points in the punctured vessels under the influence of the negative pressure in the tracheae. They then multiply in these vessels until they become packed tight, after which spread occurs to other vessels by breakdown of walls Once the bacterial column is formed in the bundles it appears to progress upwards and downwards mainly by multiplication of bacterial cells although some local motility of the organism has been observed at the apex of the column. This mode of progression indicates that transpiration has little direct effect on the rate of movement of the bacteria. Further evidence is provided from the experiments on invasion under very humid conditions where plants in which transpiration was almost negligible were invaded as rapidly as plants which were transpiring freely. Confirmatory evidence from another source was provided by an infection experiment in which two sets of plants (six plants per set) were grown in a controlled environment chamber at 77°F. under light values of 1,000 ft. c. and 500 ft. c. respectively. The plants under the higher light intensity transpired 22 per cent. faster than those under the lower light intensity, yet the incubation period for initial symptoms and for complete wilting was the same for both.

Although increased transpiration does not directly affect the upward movement of the bacteria, it is possible that it can affect their growth rate. Thus a higher transpiration rate may lead to more rapid transport of salts actually present in the xylem, leading to an increased salt concentration in one part which would favour more active growth of the parasite. Again it is likely that the nutrition of the bacteria might be favourably affected by increased rate of uptake of salts from the soil under the influence of higher transpiration rate. The consensus of opinion among plant physiologists has inclined to the view that transpiration rate bears no relation to salt absorption. Freeland (1937), however, has recently brought forward evidence which suggests that salt uptake is not independent of transpiration.

The increase in vessel size and number which was demonstrated for plants growing in wet soil might be expected to be an important factor in the more rapid spread of the bacteria in these plants. But it is not easy to obtain proof that increased size of

vessel *per se.* does facilitate bacterial movement because a whole complex of factors is involved rendering the plant more susceptible.

The limited experiments on growth of healthy tomato plants reported in this paper indicated that increase in dry weight and height was related to temperature and light, being greatest in summer at mean temperatures of 75–78°F. and mean light intensity of 800–900 ft. c., and least in late autumn (no experiments were used in winter) at an average temperature of 62°F. and 400 ft. c. light intensity.

The interrelation of light and temperature for tomato plants (var. E.S.1.) under conditions of glasshouse culture has been studied in considerable detail by Bolas (1934). He found that maximum rate of assimilation (relative increase in dry weight) from 84–90°F. occurred with 1,000 ft. c.; at 75°F. with 600 ft. c. falling off with rise of light intensity to 1,000 ft c and at 59°F. with 100 ft. c. decreasing with light intensity above this.

Considering the bacterial invasion experiments (Tables II. and III.) on the basis of the results of Bolas and the author, it is clear that susceptibility to invasion by the parasite is associated with vigour of growth in the host, since the inoculated plants growing at 73°F. and 800 ft c. would be growing close to the optimum rate. With reduction of light intensity to 130 ft. c. at 73°F. (Table III.) a considerable depression of growth in the host might be expected. The reduction in invasion speed which occurs at this temperature and light combination, is believed to be directly attributable to the light factor in depressing growth since reduced transpiration would not exert any effect and any consequential increase in water content might be expected to favour bacterial invasion.

The effect of temperature is more complex in that it affects both the growth of the host and of the pathogen.

The decrease in assimilation rate as the temperatures drop from 73°F. to 59°F. reacts in some fashion on the bacteria leading to a slower rate of growth in them (Table II.). Possibly the depression of the growth rate in the host at lower temperatures reacts deleteriously on the volume of metabolic products available for utilization by the bacteria. Temperature, however, also acts directly on the growth of the pathogen (see fig. 2). At 15°C. (59°F.) little growth is occurring and at 18°C. (64°F.) the rate of growth is only 31 per cent. of that at 32°C. (90°F.) so that a great deal of the depression in invasion rate may be directly attributable to the effect of lowered temperature on the growth of the parasite. That not all of the depression in growth is due to a direct temperature effect on the parasite is shown by the

fact that when assimilation rate is reduced by a big decrease in light intensity, temperature remaining the same at 73°F., the bacterial growth rate is reduced. This suggests that the change in growth rate in the host under altering conditions of temperature and light affects the rate of multiplication of the organisms by varying the availability of metabolic products for its nutrition. Studies on the food requirements of *B. solanacearum* carried out in these laboratories (Mushin, 1938) showed that this organism could utilize a variety of organic and inorganic compounds as sources of nitrogen and carbon food. Of such potential food substances likely to be found in the plant, sucrose and glucose served as sources of carbon and gave a rich growth in the presence of a source of nitrogen, e.g. potassium nitrate. Substances such as peptone, tyrosine and glutamic acid served both as a source of carbon and nitrogen to maintain the growth of *B. solanacearum*. The parasite grows primarily in the xylem vessels and here one might expect to find salts including potassium nitrate and sugars together with amino acids which have "leaked" into the xylem. Despite the absence of precise information on just what metabolites are selectively utilized by the pathogen in the host, it appears possible that the retarding action of reduced light on susceptibility to invasion is due at least in part to depressed bacterial metabolism arising from a lowered availability of food material in the xylem.

That factors other than, or in addition to, those examined by the author, may be concerned in determining the virulence of the parasite or the susceptibility of the host in other parts of the world, is indicated by the work of Eddins (1936). He noted that bacterial wilt occurred in all types of sandy soil in Florida, U.S.A., and was more serious when rainfall was less and temperatures were above 77°F. Here temperature is an important factor but soil moisture does not come into question. The hydrogen ion concentration of the soil was shown to be important and Eddins claims control of the disease by the use of sulphur, whereby the acidity of the soil is increased.

## Note on Control of the Disease.

Important factors which have been recorded in the course of this paper as affecting the incidence of the disease (tested mainly under glasshouse conditions) are (*a*) soil moisture, (*b*) temperature, and (*c*) atmospheric humidity. These three factors are known to apply in the field in Victoria. The combination of high soil moisture, high temperatures and high relative humidity is known to be responsible for increased losses in potato crops in certain years.

Control of the disease in Victoria is being achieved in large measure by seed selection, and by drainage (e.g. of the Koo-wee-rup area) which minimizes the operation of the soil moisture factor.

In New South Wales (1939, 1940) the disease is recorded as occurring on sandy as well as on heavy wet soils. This suggests that in that State some other factor besides soil moisture is important in predisposing plants to infection or in altering the virulence of the parasite. Possibly the pH factor (Eddins, 1936) may be concerned in sandy soils in which case the use of sulphur would be beneficial although Paul (1939) failed to control bacterial wilt in Ceylon by its use.

## Summary.

1. High soil moisture favours heavy and rapid invasion of potato and tomato plants by *Bacterium solanacearum*, while in dry soil the plants are more resistant to the spread of the organism. Since the disease occurs most seriously in the moist soil of the Koo-wee-rup area in Victoria the results indicate a positive relation between soil moisture and the incidence of the disease in the field.

2. Both temperature and light influence invasion rate as judged by incubation period of symptoms. Average temperatures between 66°F. and 73°F. with average light intensity of 800 ft. c. in the glasshouse during summer months gave most rapid spread of the disease in the host.

3. Plants grown under conditions of high humidity were more susceptible than plants under normal glasshouse conditions. Transpiration rate was shown to have no direct effect on the movement of the parasite up the vessels.

4. The rate of movement of *B. solanacearum* in the bundles of potato and tomato plants at different soil moisture levels was determined. Optimum rates in wet soil at 73°F. were 5·0 mm. per hour for potato and 2·2 mm. per hour for tomato.

5. The minimum, optimum and maximum temperatures for growth of the parasite were found to be 15°C., 32°C. and 35°C. respectively.

6. A study on physiological and anatomical changes in tomato plants arising out of growth in wet soil as against dry soil, showed that significant differences in height, leaf area and water content developed, while vessels were larger and more numerous. The increased water content is believed to be the factor which influences the susceptibility of the plant to invasion.

7. Results of growth experiments indicated that spread of the disease in the host was related to the vigour of growth in the host

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ART. III.—*Problems of Stratigraphic Correlation in the Indo-Pacific Region.*

By M. F. GLAESSNER, Ph.D.

[Read 11th June, 1942; issued separately 1st May, 1943.]

## Abstract.

The stratigraphic correlation of marine deposits of Jurassic, Cretaceous, and Tertiary age in the Indo-Pacific Region is reviewed. Results of recent bio-stratigraphic studies in the East Indies are compared with the available data on the stratigraphy of New Guinea and of some of the other islands in the south-western Pacific. The significance of larger and smaller foraminifera for the stratigraphic subdivision of the sequence of Indo-Pacific Tertiary deposits into Series and Stages is discussed Some features of the distribution of sediments and fossils which are believed to indicate important events in the geological history of the Region are enumerated

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2. Cretaceous.

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2. Correlation of Eocene and Oligocene deposits.
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4. Correlation of Miocene and Pliocene deposits not containing distinctive larger foraminifera.
5. Further problems of Tertiary correlation.

III. NOTES ON THE GEOLOGICAL HISTORY OF THE INDO-PACIFIC REGION.

BIBLIOGRAPHY.

## Introduction.

The present paper deals with stratigraphic correlation of Jurassic, Cretaceous, and Tertiary marine deposits in an area between the eastern shores of the Indian Ocean in the west and Fiji in the east and between Borneo and New Guinea in the north and tropical Australia in the south. This is the greater part of what is known in zoogeography as the Indo-Pacific Region. Although important areas of this zoogeographic province are not included in this review (Central Pacific Islands, Philippines, islands in the western Indian Ocean), the use of this convenient name appears to be justified.

Several distinct structural units are recognizable in the Indo-Pacific Region: the opposed stable areas of Sundaland in the north-west and Australia in the south-east, including the Sahul shelf and the southern portion of New Guinea; the belt of moderate young folding around the margins of Sundaland, and the volcanic arcs accompanying this belt; the arc system of the strongly folded Timor-East Celebes geosyncline; two branches of this geosyncline, one in New Guinea and another one, the Westralian geosyncline (Teichert 1939), in North-western Australia. The latter is now structurally incorporated in the stable area while the former has been transformed into a mountain range indicating considerable young folding and faulting. East of New Guinea the folded zone continues in the general direction towards New Caledonia, the New Hebrides, and New Zealand. Beyond this belt there is another stable area, including Fiji and Tonga The real geological boundary of the Pacific Ocean, based on a dividing line between the areas of andesites and basalts, passes north and east of it. Some authors assume the existence of a largely submerged extension of the Australian stable area, the Melanesian continent, between this boundary and Northern New Guinea.

The great advances made in recent years in the stratigraphy and palaeontology of key areas in the Indo-Pacific Region, connected with the names, among many others, of W. L. F. Nuttall, L F. Spath, Oostingh, Tan, Umbgrove and van der Vlerk, F. Chapman and Miss I. Crespin, convinced the author that the time for a critical stratigraphic review of the whole region had arrived and that this work could be expected to stimulate further discussion of one of the most fascinating problems of regional geological history.

The present review is not a complete discussion of Indo-Pacific post-Triassic stratigraphy. Its scope is limited to marine sediments because of the uncertainty of age and relations of most of the volcanic rocks of the region, and the comparative insignificance of other non-marine deposits outside Australia. It deals with problems of correlation without presenting detailed descriptions of stratigraphic sequences. For details the reader is referred to stratigraphic summaries covering many parts of the region and quoted in the bibliography.

It is not intended to discuss here the structural theories proposed by numerous authors in explanation of the complex features of the area between Australia, Asia and the Pacific Ocean. Biostratigraphic correlation merely contributes towards the solution of fundamental geological problems by placing the geological events in their proper sequence and relation and by

establishing analogies and differences in the geological history of areas which are to be considered as structural units (stable areas, mobile belts, geosynclines, etc.).

The uncertain and varying definitions of the term "geosyncline" call for some explanation concerning its use in the following discussion. Recently Jean Tercier (1939) compared the latest data on marine sedimentation in the East Indies and elsewhere with Haug's classical and widely accepted views on facies, depth zones, types of deposition, and geosynclines. The present writer, while not entirely in agreement with Tercier's conclusions, is unable to discuss in the limited space available this vast and important problem and has to refer the reader to Tercier's review, particularly to his chapter on "Facies and types of marine sedimentation" (l.c. pp. 87–93), where the five fundamental types, i.e. paralic, epicontinental, geosynclinal, oceanic, and continental, are discussed and defined.

"Present judgment as to methods of stratigraphic palaeontology places weight on the value of evolutionary stages determined in any stock, relies on the testimony of a relatively small number of carefully identified guide fossils that for various reasons may be regarded as most reliable, and endeavours to take full account of ecologic elements in the interpretation of faunal and floral assemblages." (R. C. Moore, Stratigraphy, in: Geol. Soc. Amer. Fiftieth Anniversary Volume, June 1941, p. 203.)

The American system of stratigraphic terminology, recently formulated by H. G. Schenck and S. W. Muller (1941) shows a much needed way in which confusion in stratigraphy can be avoided. In the Correlation Table accompanying the present paper an attempt is made to distinguish between local terms agreeing in form and definition with the Formations or Groups of this system, and mere descriptive designations. The author does not consider a paper on regional correlation as the proper medium for the creation of new stratigraphic terms which must be based on local stratigraphic data but he ventures to express the hope that in due course all definable lithogenetic units will receive proper and unequivocal formation names. The question whether under certain circumstances some local rock-stratigraphic terms should receive the rank of regional "Stages" replacing the European stage terms or whether in this case an entirely new set of names of independent derivation has to be created, is still open for discussion. The common use, in some parts of the region, of the words "Series" or "Beds" instead of "Formation" is a problem of minor importance. The establishment of "Zones" in post-Jurassic Indo-Pacific sediments is a vital task of future palaeontological research.

ACKNOWLEDGEMENTS.

The author had the opportunity of stimulating discussions concerning problems of Indo-Pacific stratigraphy with Miss I. Crespin, Canberra; Dr. F. W. Whitehouse, Brisbane; and other geologists and palaeontologists in Australia and the East Indies, who also assisted very kindly in obtaining bibliographic references and copies of publications. To all of them the author wishes to express his sincere gratitude and appreciation.

He is further indebted to Mr. W. Baragwanath for arrangements facilitating the re-drawing of the accompanying Correlation Table; and to Mr. W. J. Parr for assistance in the preparation and publication of this paper.

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## I. Jurassic and Cretaceous.

### 1. Jurassic.

Recent studies of the Mesozoic of the East Indies (Wanner 1931, Umbgrove 1935, 1938) established the existence of a geosyncline extending from Timor through some of the Molucca Islands (Ceram), to East Celebes. The western margin of this geosyncline is formed by the stable area of Sundaland (Malaya, West Borneo, West Celebes) which was only in part affected by intermittent Jurassic and Cretaceous transgressions, and by the zone Sumatra-Java-Soemba, the Mesozoic history of which is only incompletely known but does not suggest geosynclinal conditions. A southern branch, the "Westralian geosyncline" (Teichert 1939), indicates the revival, in Jurassic time, of an important Palaeozoic geosyncline. Faunal relations of the East Indies and Western Australia around the Australian shield with New Caledonia and New Zealand in Jurassic time are well known but the part played by New Guinea in relation to other Mesozoic areas is at present not fully understood.

Stratigraphic correlation in the Jurassic is based on a standard system of ammonite zones which owing to greater climatic uniformity in Jurassic time can be adapted for world-wide use with comparative ease. Stratigraphic terms used in the following discussion are based on the latest revision of this system recently published by S. W. Muller (1941).

#### The Jurassic of New Guinea.

Owing to peculiarities of facies and preservation of fossils the Jurassic sequence of New Guinea is well known palaeontologically although Jurassic rocks have only rarely been seen in situ.

UPPER LIAS is known from Western New Guinea (Etna Bay) where *Coeloceras moermanni* Kruizinga was found (Kruizinga 1926). A Liassic lamellibranch (*Ctenostreon cf. terquemi* Tate) was determined by Bullen Newton (1916, p. 9) from Central New Guinea. Liassic rocks have not been found in situ.

BAJOCIAN is represented by occurrences of *Stephanoceras* (Etheridge 1890, Gerth 1927), including *S. etheridgei* Gerth from Western New Guinea and a similar species described by Etheridge from pebbles found in the Strickland River in Papua. The BATHONIAN of New Guinea is at present not clearly distinguishable.

CALLOVIAN is well represented. Terpstra (1939, p. IV. 2) described micaceous clay-shales in situ, with "*Macrocephalites*", undetermined belemnites, *Homomya* and *Inoceramus* from the Woesi River (Upper Lorentz River basin), where the Jurassic is transgressively overlain by Oligocene. Callovian ammonites from pebbles were described by G. Boehm (1913) from Western New Guinea where they are considered to be derived from known beds outcropping nearby. Some of the ammonites figured by R. Etheridge jun. (1890, pl. 29) from the Strickland River gravels represent Callovian forms. Their nomenclature has been revised by later authors as follows:—

FIG. 1.—"*Stephanoceras* allied to *S. lamellosum*," now *Kamptokephalites etheridgei* Spath (1928, p. 200, pl. 12, fig. 3).

FIG. 2.—"*Stephanoceras* allied to *S. blagdeni*," now *S. aff. etheridgei* Gerth (1927).

FIG. 3.—"*Stephanoceras* allied to *S. lamellosum*," now *Macrocephalites keeuwensis* β G. Boehm, or *M. waageni* Kruizinga *non* Uhlig (Kruizinga, 1931).

FIG. 4.—"An ammonite allied to *A. lingulatus*."—?

FIG. 5.—"*Stephanoceras* allied to *S. calloviensis*," now *Dolikephalites flexuosus* Spath (1928, p. 210, pl. 12, fig. 4).

*Macrocephalites keeuwensis* G. Boehm, according to Spath not a single species but a group of more or less related forms, was first described from the Callovian of the Sula Islands and is also known from Western New Guinea and from Sepik River pebbles (Schlüter 1928).

OXFORDIAN was described by Broili (1924) from Western New Guinea where *Belemnopsis gerardi* (Oppel) and *Buchia* ("*Aucella*") *malayomaorica* (Krumbeck) (described as ?*Pseudomonotis* sp., l.c. pl. 2, figs. 10, 11) occur in dark-grey clay shales. The species have also been seen by the writer in collections from Central New Guinea. Gerth (l.c.) mentions a *Peltoceras* sp. Schlüter (l.c.) found in the Sepik pebbles *Perisphinctes burui* (*taliabuticus*) G. Boehm and *Inoceramus*

*galoi* G. Boehm, well known species of the Mefa beds of Buru and the Wai Galo beds of the Sula Islands. These beds are placed by Spath in the *cordatus*-zone of the Oxfordian.

No representative species of the uppermost Oxfordian zones and of the Kimmeridgian are known among the ammonites of New Guinea.

TITHONIAN. Schlüter (l.c.) described from the Sepik pebbles the species *Kossmatia desmidoptycha* Uhlig, *Haplophylloceras strigile* (Blanford), and *Blanfordiceras cf. wallichi* (Gray), considering their age as transitional to Cretaceous. They are also known from pebbles derived from Tertiary conglomerates on the Toarim River, Northern New Guinea. According to Spath they represent the uppermost Jurassic

Jurassic beds of the Sula Islands and New Guinea are generally developed as shales with hard siliceous fossiliferous nodules ("Geodenschiefer"). Facies and affinities of the Jurassic in New Guinea suggest that part of Western and Central New Guinea was a geosynclinal area. It extended possibly into Eastern New Guinea where within the limits of E. R. Stanley's "Astrolabe-Kemp Welch Series" (1923) the present writer found *Pentacrinus sp.* and *Entolium sp* in slightly altered sandy limestones overlying phyllites at Goilala on the Upper Aibala River. The phyllites overlie highly metamorphic schists (E. R. Stanley's "Owen Stanley Series").

CORRELATION.

Towards the east, only Tithonian ("Portlandian") is known in New Caledonia where the La Foa formation (Piroutet 1917) with *Berriasella cf. novoseelandica* transgressively overlies Triassic. According to Piroutet no earlier Jurassic horizons are known. In New Zealand (Kawhia Harbour, Trechman 1923) the Oxfordian *Buchia-Belemnopsis* assemblage as well as the Tithonian clearly indicate East Indian affinities.

Towards the west the same Jurassic faunal sequence extends into the area of the Spiti shales of the Himalaya (Uhlig 1910). According to Spath (1933, p. 662) this classical section shows a faunal gap apparently corresponding to the break in the New Guinea ammonite fauna:

| | |
|---|---|
| Spiti shales | Chidamu beds—Tithonian |
| | Faunal gap.—Uppermost Oxfordian and Kimmeridgian. |
| | Belemnite beds.—Middle Oxfordian |
| | (Callovian species known from the basal beds) |

Umbgrove (1938, p. 24 f.) although considering our knowledge of New Guinea as inadequate, admits the possibility of this area having formed a geosyncline in Jurassic time after a probably continental period in the Triassic. There are strong indications

of the existence, in Jurassic time, not only of a restricted "Westralian" but of a Circum-Australian geosyncline. It differed from the Timor-East Celebes geosyncline in a less complete record of Jurassic stages, in more consistently terrigenous facies, and partly also in less pronounced post-Jurassic ("Pacific" or "Young Kimmeric") folding.

## 2. Cretaceous.

Wanner (1931) and Umbgrove (1935, 1938) have published summaries of the Mesozoic history of the East Indies to which the reader is referred for more detailed information. Some additional data and new aspects are discussed here.

(*a*) Sumatra and Borneo.—Lower Valanginian with *Neocomites* is known from Sumatra. Other evidence of Lower Cretaceous is seen in the occurrence of *Orbitolina* in Sumatra, Java, Borneo and Celebes. Umbgrove (1935) has pointed out that in the absence of reliable specific determinations these occurrences cannot be considered as evidence of a "Cenomanian transgression" but indicate only Barremian to Cenomanian age of these generally transgressive rocks

The Seberuang Formation of Western Borneo is now known (Zeijlmans 1939) to represent a complete sequence of Cretaceous from transgressive Valanginian with *Neocomites* and *Thurmannia* (Bedoengan beds) through *Orbitolina*-bearing rocks to Turonian and Senonian with mollusca and *Globotruncana* (Selangkai beds).

Cenomanian is also known from Western Borneo as sandstones with *Nerinea* and limestones with *Knemoceras pinax* Krause and *Schloenbachia*. In South-east Borneo *Orbitolina*-bearing beds are followed by richly fossiliferous limestones with *Nerinea* and rudistids, of Martapoera. Martin considered these beds as Senonian of Indian (Ariyalur) affinities.

(*b*) In the "Timor-East Celebes Geosyncline" a transition from highest Jurassic to lowest Cretaceous beds with *Duvalia* (Timor) and *Hibolites subfusiformis* (Misol) probably exists. These beds are followed, according to Wanner (1931), by limestones with "*Globigerina*, *Discorbina*, and *Pseudotextularia*" which are very widely known from the eastern part of the Archipelago. "*Discorbina*" is of course the well-known *Globotruncana* and "*Pseudotextularia*" includes *Gümbelina*. After considerable discussion on the age of these beds, Umbgrove (1938, p. 19) describing the sequence of Misol according to Weber, considered them to represent Barremian to Cenomanian, lying above beds with *Hibolites subfusiformis* (Valanginian-Hauterivian) and below beds with *Inoceramus* and *Durania*, containing Maestrichtian and possible slightly older forms (Wanner 1931, p. 600).

Beds containing *Globotruncana* cannot be as old as Barremian and are possibly not older than Cenomanian. In Mexico, the Gulf Coast region, North Africa, the Alps, Apennines, Greece and the Caucasus detailed micropalaeontological investigations have failed to detect any evidence of pre-Cenomanian *Globotruncana.* The widely quoted *G. canaliculata* Reuss (= *G. linneana* d'Orbigny sp.) however has been described from the Aptian and Albian of the Pyrenees and the Balearic Islands as well as from the Albian Red Chalk of England. It is a common species in the Turonian and Senonian elsewhere. The Seewer beds of the Western Alps which resemble the *Globotruncana* rocks of the East Indies closely, are Turonian, and most of the similar "Couches Rouges" are Senonian. The existence of an unbroken sequence of Cretaceous rocks in the Timor-East Celebes geosyncline can be proved only by detailed micropalaeontological investigations. *Globotruncana stuarti* (Lapparent) found by Tan Sin Hok in rocks from Western New Guinea and determined by Glaessner from the pink limestone first discovered near Port Moresby by J. N. Montgomery (in: B. K. N. Wyllie 1930, vol. 4, pt. 5, p. 34) proves Upper Campanian-Maestrichtian age of the rocks containing it. This species is also clearly recognizable in a photograph of an "inclusion of Cretaceous *Discorbina*-limestone in a Tertiary e—5 limestone" from Celebes, published by van der Vlerk and Dozy (1934, pl. 2, fig. 1).

(*c*) In North-western Australia Dr. Raggatt (1936) found the Cretaceous commencing with transgressive Upper Albian. The following summary of the sequence in the North-west basin was recently given by C. Teichert (1939, p. 85).—"The lower part of the Cretaceous series consists of about 1,100 feet of greensands, siltstones, and cherts of the Winning series. Belemnite beds, probably not far above the base of the series, are considered to be of Albian age and the early part (Neocomian) of the Lower Cretaceous seems therefore not to be represented. A Lower Cretaceous transgression seems also to have affected the coastal regions much further south at Perth, where I. Crespin reports the finding of foraminifera of that age in strata about 1,650 to 1,750 feet below sea level". The belemnite beds referred to contain according to Whitehouse *Dimitobelus diptychus* (McCoy) and have been named "Cardabia beds" by Glauert.

Near Darwin, the Point Charles bed contains a fauna of ammonites considered by Whitehouse (1926, p. 279) as typical of the *substuderi*-zone of the Upper Albian, and also the world-wide Upper Albian to Cenomanian *Aucellina gryphaeoides* Sow. "Above the ammonite bed in this region is a whitish rock with impressions of belemnites. . . . It is probably . . . Uppermost Albian or Lower Cenomanian. At Melville Island a bed has yielded *Acanthoceras* and *Inoceramus.* This is obviously

Cenomanian in age, while from the ammonites present it appears more definitely to represent the *baylei*-zone of the Upper Cenomanian." (Whitehouse l.c.). In Sir T. W. Edgworth David's Correlation table of Cretaceous rocks of the Commonwealth (1932, table H) the sequence near Darwin is shown as follows:—

Cenomanian— { Melville Island drab-coloured mudstone.
Point Charles bed.

Upper Albian— { Ferrugineous shales of the *aequatoriale*-zone.
Fanny Bay radiolarian shales with belemnites and *Ichthyosaurus*.

Cenomanian is not definitely known from the North-west basin where the Winning series is followed by chalks, clay shales, *Inoceramus* marls, glauconite sand, and sandy polyzoal limestone (Cardabia series of Raggatt, *non* Glauert). The limestone, probably Maestrichtian according to Spath, contains *Ostrea vesicularis* Lam. and other fossils. From the greensand Spath (1940) described Lower Maestrichtian ammonites including *Kossmaticeras, Kitchinites, Pachydiscus aff. gollevillensis* Grossouvre, etc. The chalks probably correspond at least in part to the Gin Gin chalk several hundred miles further south containing *Uintacrinus* and *Marsupites* (Upper Santonian, according to Spath Santonian and Campanian). The foraminiferal fauna of the North-western Cretaceous determined by Miss Crespin (1938*a*) appears to suggest Lower Senonian rather than Turonian or Cenomanian age of the chalks and Upper Senonian (Campanian-Maestrichtian) for the higher beds, judging from the occurrence of several world-wide index species.

In Queensland and Central Australia the Roma beds with *Ancyloceras, Tropaeum, Tetrabelus, Peratobelus, Maccoyella, Pseudavicula* etc. represent, according to Whitehouse (1930, p. 37) Aptian, and the Tambo beds are Upper Albian (*Puzosia, Anisoceras, Labeceras, Aucellina, Inoceramus,* etc.).

(*d*) In New Guinea, as in Australia, no early Cretaceous marine fossils have been discovered, the fauna of the so-called "transition beds" representing, according to Spath, the uppermost zone of the Jurassic. Early reports suggest the occurrence of Cretaceous of Australian affinities (Apt-Albian) in Central New Guinea. Apart from pebbles with Jurassic ammonites mentioned above, Capt. Everill found fossils in situ on the Strickland River, five days' journey by whaleboat above Carrington Junction (Cecilia Junction). C. S. Wilkinson (1888, p. 204) who examined the samples, stated after quoting from Capt. Everill's report: "The high precipices along the river are formed of sandy calcareous strata, of a dark greenish colour, full of fossil shells of Cretaceous age; amongst those collected are *Gryphea, Modiola, Aviculopecten, Protocardium, Cidaris,* ammonites, *Inoceramus,* etc. . . . The specimens of fossiliferous greensand rock

collected from the Strickland River lithologically resemble the Cretaceous beds of New South Wales and South Australia." This description makes it quite unlikely that the black siliceous nodules containing Jurassic ammonites which were found in the Strickland River gravels as well as—much later—in the Sepik River are derived from these outcrops. Similarity of fauna and facies of these pebbles suggests a common source, probably in the Strickland-Sepik divide on the north side of the Main Range.

A few years later R. L. Jack and W. H. Rands (1894, p. 93) reported on Cretaceous fossils collected by Sir William MacGregor on the Upper Purari River. MacGregor's route map shows the locality to be near Biroe Village (north of lat. 7°, long. 144° 50′). "The limestones, although containing numerous fossils, have only one which is in a condition to be recognized. This one, however, a belemnite, is of the utmost importance as this cephalopod is most characteristic of the Cretaceous rocks of Europe and Queensland. The genus has not been met with before, so far as I am aware, in New Guinea. I sent the specimen to Mr R. Etheridge, jun., who confirmed my identification. Other Cretaceous fossils have been obtained from the Strickland River . . . It is evident that the Purari blue limestones must be classed at Cretaceous, and of course, if my surmise that they belong to the same formation is correct, so must the green sandstone." (R. L. Jack, l.c., p. 93, 30th April, 1894). The description of individual samples shows that the limestones contain abundant bivalve shells "and some gastropods like *Anchura*." A. Gibb Maitland (1905, p. 47) used the name "Purari River beds" for this occurrence of Cretaceous.

Sir W. MacGregor's observations and R. L. Jack's determinations received striking confirmation when early in 1940 Dr. S. W. Carey re-visited the locality of the reported Cretaceous on the Upper Purari, and collected samples of rocks and fossils, in connection with geological exploration work carried out in Papua by the Australasian Petroleum Company. The fossils were subsequently examined by the present writer. Among them was a belemnite belonging to the family Dimitobelidae Whitehouse, abundant bivalve shells the most common of which is *Pseudavicula cf. papyracea* Etheridge, and the "gastropods like *Anchura*" mentioned by R. L. Jack. The belemnite was sent to Dr. F. W. Whitehouse who determined it as *Tetrabelus n.sp.* This genus is known (Whitehouse 1924, 1930) from the Roma beds (Aptian) of Australia and from the Upper Albian of India. The preservation of the other mollusca in very hard rock makes specific determinations difficult and uncertain. Among others, the following genera are represented in the fauna: *Nucula, Trigonia, Lima, Ostrea, Exogyra, Mytilus, Ptychomya, Natica, Nerinea*. A small *Lingula* and a tooth of *Lamna* were also found, as well as smaller foraminifera, ostracods, and echinoid remains.

Fossils collected by Patrol Officers of the Papuan Service in the Kerabi Valley north of Mt. Murray in Papua were mentioned by E. R. Stanley (1923, p. 26). They include large ammonites. Stanley states "The majority of these specimens appear to be related to the Upper Cretaceous". They are now being examined by F. W. Whitehouse whose preliminary determinations (*Acanthoceras sp., Mantelliceras papuae nom. nud.*) were included in Sir T. W. Edgworth David's correlation chart of the Cretaceous rocks (1932, table H). These determinations prove Cenomanian age of the Kerabi Valley beds.

The Cretaceous of New Guinea includes beds with mollusca resembling those of the Australian Roma and Tambo series (Apt-Albian), Cenomanian with *Acanthoceras*, and Upper Senonian in *Globotruncana*-facies.

(*e*) The Cretaceous of New Caledonia, although still quite incompletely known, appears to have a similar range and development. According to Piroutet (1917) three "stages" can be distinguished. Each of them is locally found transgressive on Triassic rocks. The lowest is the Dumbéa with *Cardium caledonicum* Munier-Chalmas and *Pellatia garnieri* Munier-Chalmas, followed by andesites. The next higher stage is the Moindou in which three main subdivisions and a large number of fossiliferous horizons are recognizable. Lamellibranchs (*Trigonia, Cardium aff. dubuchense, Exogyra cf. couloni* Defr., etc.) and gastropods are almost the only groups of fossils mentioned. A *Trigonia* from the higher part of this stage is said to be comparable with one from the Maryborough beds (Roma) of Queensland but other Australian Cretaceous lamellibranchs may also be present in the Moindou. Judging from the then available data Piroutet did not find any other striking resemblances with Australian species. He believes the Dumbéa and lower Moindou to represent "Eocrétacé" (Barremian?) and the basal upper Moindou to be "Mésocrétacé" (Apt-Albian?). The Upper Moindou may be Cenomanian.

The highest Cretaceous stage in New Caledonia is the St. Vincent containing *Kossmaticeras cf. bavani* Stol. (determined by Prof. Kilian), *K. loganianum* Whiteaves, *K. cumshevaense* Whiteaves, *Puzosia cf. gaudama* Forbes and a large number of other fossils including an *Inoceramus* described by A. Heim and A. Jeannet (1922). This is clearly a Senonian fauna showing considerable similarities with the Santonian (?) Batley fauna of New Zealand and similar Pacific assemblages (Benson 1928).

In New Zealand according to Finlay and Marwick (1940, p. 83) "the oldest post-Hokonui formation for which a definite Cretaceous age has been established is the Taitai series". It contains the well-known Australian genera *Maccoyella* and *Aucellina* and is Upper Aptian. Albian, Cenomanian, and younger Upper Cretaceous stages are also represented.

CORRELATION.

Lower Cretaceous to Cenomanian sediments west of the Timor-East Celebes geosyncline are mostly rich in *Orbitolina* and *Nerinea* and show Mediterranean affinities. What is known of deposits of the same age from New Guinea and New Caledonia shows epicontinental rather than geosynclinal development and suggests similarities with the fauna of the Cretaceous of Australia and New Zealand) Dimitobelidae, aviculid lamellibranchs, no *Orbitolina*), rather than with Borneo and Sumatra. In both areas however relations with the Cretaceous of India are found.

The molluscan fauna of the Senonian shows some characteristic Indo-Pacific or rather Indian and Pacific features, in Borneo as well as in North-western Australia, New Caledonia, and New Guinea. The pelagic smaller foraminifera (*Globotruncana*, *Gümbelina*) become rock-forming for the first time, these rocks from the Timor-East Celebes geosyncline and New Guinea closely resembling rocks of the same age from the Alpine geosyncline in Europe.

## II. Tertiary.

### 1. METHODS OF CORRELATION.

Biostratigraphic correlation of Mesozoic marine deposits is based on zones which are either worldwide or at least useable within the wide limits of a palaeo-zoogeographic province. Correlation of Tertiary deposits is a much more difficult problem on account of climatic differentiation, topographic isolation, and close stratigraphic subdivision of deposits representing a comparatively short time interval. No world-wide scale of fossil-zones based on well-defined ranges of a set of index species exists. A sequence of Tertiary faunal assemblages was long ago established in Europe and it is not surprising to find that workers in other continents first turned to this sequence for guidance by means of direct comparison and correlation. As long as no scale of zones is available, the next higher unit in stratigraphic classification, the stage, must be the basic unit for measuring Tertiary geologic time. The recognition of the European stages in the East Indies proved so difficult that a number of workers gave up and even condemned attempts at inter-continental correlations.

Four different lines of approach to stratigraphic problems in the East Indies, the key area for the Indo-Pacific Tertiary, have been followed.

(*a*) K. Martin (1919, and earlier publications) was the first to examine critically collections of mollusca and other fossils. He found them so different from the standard European

assemblages that he decided to determine their age by means of Lyell's method, i.e., according to their more remote or closer affinities with the Recent molluscan fauna of the Indo-Pacific Region. This affinity was expressed in percentages of living species for each fauna described. The stratigraphic results of Martin's work were adversely affected by insufficient stratigraphic field evidence on the succession and relations of mollusca-bearing beds and by the much-discussed dangers of the percentage-method. This stratigraphic tool, far from being an exact statistic method for which it was occasionally mistaken, gives generally no more than what even its most determined critics concede, i.e., "a general indication as to early, middle, or late Tertiary age" (Finlay and Marwick 1940, p. 91). In the special conditions of the East Indies this should be read as "early, middle or late *Neogene* age", for which subdivisions the figures are approximately 8–20, 30–45, 50–60 per cent, respectively.

(*b*) H. Douvillé (1905, and other publications) tried to correlate East Indian Tertiary deposits by comparing assemblages of larger foraminifera with those found in Western Europe. Douvillé's method soon lost favour as a result of confusion then arising over the delimitation of Tertiary stages and the distribution of larger foraminifera in the type areas (F. Sacco, 1905), as well as because of the limited number of species common to both regions and insufficient knowledge of the vast intervening regions of the "Middle East". It appears now, after nearly forty years, that in spite of these difficulties Douvillé's correlations of Aquitanian, Burdigalian and Helvetian with Indo-Pacific formations appear in many cases to be approximately correct.

(*c*) Van der Vlerk endeavoured to avoid the danger of confusion by dividing and correlating the Tertiaries of the East Indies according to the local sequence of foraminiferal assemblages. In collaboration with Umbgrove (1927) he created local "stages" designated by the letters "a" to "f" (subdivided into "zones" designated by numbers), and based on the distribution of larger foraminifera. The stages "g" and "h", based on other criteria, were added later in order to complete conveniently the subdivision of the Tertiary. The stages were not explicitly referred to type sections but were linked in a general way with the stratigraphic sequence observed by the authors in East Borneo and elsewhere. Later correlation (Leupold and van der Vlerk, 1931) generalized these stages and zones so that they finally included stratigraphic units in which the distinctive foraminifera had not been found.

While not inclined to use European series and stage terms generally, van der Vlerk (1931, p. 207) showed in a chart "the most probable comparison" between European and East Indian subdivisions. Stages "a" and "b" are placed in the Eocene, "c" and "d" in the Oligocene, "e" and part of "f" including the West Progo and Njalindoeng mollusca-bearing beds are considered as Lower Miocene, the rest of the "f-stage" including the Tjilanang and Lower Palembang beds and the "g-stage" are Upper Miocene and the "h-stage" with the Sondé beds is Pliocene.

Gerth (1935) presented additional evidence for the distinction of Eocene, Oligocene and Miocene in Java by comparing occurrences of larger foraminifera with supposedly similar assemblages from Sind, South-west France, and the West Indies.

(*d*) The collaboration of the palaeontologists Koenigswald (vertebrates), Oostingh (mollusca), and Tan Sin Hok (larger foraminifera) with the field geologists of the Netherlands East Indies Geological Survey placed the study of the Tertiary in the East Indies and indeed throughout the Indo-Pacific Region on a firm base. Koenigswald's work established the sequence of definitely Lower Pliocene, Upper Pliocene, and Pleistocene vertebrate faunas in Java. They were stratigraphically correlated with marine molluscan faunas described by Oostingh, by means of which correlation was extended over larger areas. Tan Sin Hok developed elaborate and important methods of morphological analysis of the structure of larger foraminifera (1932, 1936*a*, 1939). His latest views on the general subdivision of the Tertiary of the East Indies are here summarized. He finds (1936, 1939*a*) that the following boundaries are palaeontologically recognizable:—

(1) Eocene/Oligocene.
(2) Aquitanian/post-Aquitanian (e/f).
(3) Between two subdivisions of the "Middle Neogene" corresponding to van der Vlerk's "$f_1$–$f_2$" and "$f_3$" respectively.
(4) Between Middle and Upper Neogene (top of *Lepidocyclina*-bearing sequence, top of "f-stage").

Thus he recognizes:—

Neogene
- Upper Neogene (formerly g–h).
- Upper Middle Neogene ($f_3$).
- Lower Middle Neogene ($f_{1-2}$).
- Lower Neogene (Aquitanian, "e," included in Miocene).

Palaeogene
- Oligocene (c–d, distinguishable from Aquitanian only where reticulate nummulites are present).
- Eocene (a–b).

Tan Sin Hok concludes (1939*a*, p. IV. 100) "The further differentiation of these main divisions can only be successful from the investigation of actual geologic sections, and moreover, if

the several species of larger foraminifera can be defined in a more objective manner. To this purpose the phylogenetic line of investigation will be of great use. In many cases a further subdivision of these stages can at present better be done by the use of local stratigraphic names."

Such names have recently been introduced by Oostingh (1935, 1938, quoted with alterations from Le Roy, 1941, p. 5, p. 110; and modified after Oostingh 1939, p. IV. 141).

Plio-Pleistocene—Bantamian (Bodjong beds).
Pliocene (post-Pontian) { Sondian (Kali Glagah Upper Pliocene vertebrates). Cheribonian (Tjidjoelang Lower Pliocene vertebrates).

Miocene { Unnamed stage (e g, non-marine Genteng beds). Preangerian (Upper Middle Neogene of Tan). Rembangian (Lower Middle Neogene of Tan).

These "stages" are based on well-defined molluscan assemblages and guide species many of which were collected from mapped and stratigraphically well known areas in Western and Central Java

## 2. Correlation of Eocene and Oligocene Deposits.

### Eocene.

Tan Sin Hok has pointed out that definite evidence for age distinction and superposition between beds with and without *Assilina* ("a" and "b" according to van der Vlerk and Umbgrove) is lacking. It appears from recent critical investigations on nummulites (Caudri 1934) that there is no evidence yet for an extensive representation of Lower Eocene in the East Indies. The oldest nummulites correspond, according to Caudri, to those found in India close to the Laki/Kirthar boundary. P. Arni (Ueber die Nummuliten und die Gliederung des Untereocaens. *Eclogae Geol. Helvet.* 32, p. 150, 1939) points out that certain assemblages from isolated outcrops of Eocene in Java contain species occurring also in the Uppermost Lower Eocene of Europe. The upper limit of the Eocene is marked by the sudden disappearance of *Discocyclina.* Occurrences of marine Eocene are scattered through the East Indian Archipelago from the Andaman to the Kei Islands, but the history of the period cannot be traced yet in detail (Umbgrove 1938).

Chapman and Crespin (1935) described nummulites, *Discocyclina, Asterocyclina* and *Pellatispira* from the Giralia limestones found by Rudd and Condit in North-western Australia. *Discocyclina* limestones occur there also at Red Bluff and Cape Cuvier (Crespin 1938).

In Western and Central New Guinea Eocene is known as foraminiferal limestones with nummulites, *Alveolina, Discocyclina, Lacazina,* etc. (Rutten 1927, Crespin 1938*b*). *Lacazina wichmanni* Schlumberger is definitely Eocene and not Cretaceous

as suspected by Umbgrove (1935, p. 143). Limestone pebbles from the upper Fly River from which Bullen Newton (1918) described foraminifera and Gregory and Trench (1916) corals are not Eocene but Lower Miocene or Upper Oligocene (e-stage) All the corals are described as new species except one which is a new variety of a *Porites*. They can obviously not be used for age determination. The foraminifera are described as *Alveolina wichmanni* Rutten, *Lacazina wichmanni* Schlumberger, *Orthophragmina* sp. *Carpenteria conoides* Rutten, and miliolines with transversely plicated chamber walls "suggesting a relation to *Pentellina saxorum*." The description of the miliolids which cannot be verified from the illustration, suggests *Austrotrillina* Parr (1942) but not the erroneously quoted *Miliola saxorum* which has a normal chamber wall. "*Orthophragmina*" (Bullen Newton l.c. p. 209, pl. 9, fig. 4) refers to an oblique section showing only rectangular median chamberlets and is therefore a *Sorites*. Differences between the supposed *Lacazina* and Schlumberger's species were noticed by Bullen Newton, their alveolinid characters were observed by Miss Crespin (1938*b*, p. 5), and spiral coiling is indeed plainly shown in fig. 2 (l.c.). The species figured is probably *Neoalveolina pygmea* Hanzawa.

In south-eastern New Guinea Eocene is represented by the Port Moresby beds. Gibb Maitland (1905, p. 47) originally used this name for the entire sedimentary series of the Port Moresby district considering its age as Pliocene. It is now known to range, with at least two breaks, from Upper Cretaceous to Pliocene. The name Port Moresby series was later restricted to the Eocene rocks of Port Moresby consisting of siliceous argillites, cherts, tuffs, and marls with abundant *Globigerina*, *Globorotalia*, *Gümbelina* and radiolaria, with intercalated bands and lenses of limestone containing nummulites, *Pellatispira* and *Discocyclina*. (J. N. Montgomery, F. Chapman, in: Wyllie 1930, vol. 4. List of Fossils quoted by I. Crespin 1938*b*, p. 4.) The Port Moresby beds are associated with serpentines and gabbro. Slight contact metamorphism is found in palaeogene *Globigerina-Globorotalia* limestones. The intrusions are therefore partly Palaeogene or younger. Some of the limestones in Stanley's Astrolabe-Kemp Welch series (Boioro and Mafulu limestones) are probably Palaeogene.

The Eocene of New Caledonia (J. Deprat 1905, Piroutet 1917) shows a similar facies of nummulitic limestones, marls and cherts, associated with an enormous development of serpentine It is reminiscent of the "serpentine series" and cherts described by Tipper (1911) from the Andaman Islands and of similar rocks of the Arakan Yoma where according to Evans and Sansom (1941) "the main intrusions of serpentinized gabbros and peridotites occurred probably in late Cretaceous and Eocene

times." Eocene foraminiferal limestones resting on tuffs and lava flows are known from Eua, Tonga Islands (Hoffmeister 1932).

OLIGOCENE.

In north-western India (Sind) a break corresponding to a major orogenic phase divides the Middle Eocene (Lutetian) Kirthar from the Oligocene Nari. "The lower Nari beds are often crowded with nummulites. These usually belong to the species *N. intermedius* and *N. vascus*. . . . The genus *Lepidocyclina*, Carter's *Orbitolites mantelli*, makes its appearance at a very low horizon in the Lower Nari, often at the very base of the formation. . . . In the Upper Nari the lepidocyclines are also very abundant but are not accompanied by nummulites. . . . All the Nari lepidocyclines appear to belong to one species-*L. dilatata*." (Vredenburg 1906, pp. 90f.). The Nari nummulites have since been recognized by Nuttall (1925) as *N. intermedius* and *N. clipeus*. *L. dilatata* was described from the Nari by the same author (1926). As these forms (except *N. clipeus*) are known from Europe, they enabled Nuttall to confirm Vredenburg's correlation of the Nari (as far as it contains *N. intermedius* and *L. dilatata*, Lower Nari according to Vredenburg), with the Stampian (Rupelian) of Europe. "In the Upper Nari, thin discoidal forms predominate, often reaching a diameter of 10 centimeters. This is *L. elephantina* Munier-Chalmas, probably identical with the Burmese form described by Carter as *Orbitolites mantelli var. theobaldi*." (Vredenburg, l.c., p. 91). *Lepidocyclina elephantina* was first described from the Chattian (Upper Oligocene) of Isola di Malo in Northern Italy and also from the Aquitanian Schio beds. The Upper Nari was correlated by Vredenburg with the Chattian.

In Burma the Oligocene is more complete. It is subdivided (Glegg 1938, Cotter 1938) into:

Okhmintaung sandstone (Singu molluscan fauna).

Padaung clay (including beds with *L. elephantina*, Yenangyat and Minbu faunas).

Shwezettaw sandstone.

These three "stages" are believed to correspond approximately to the Chattian, Rupelian, and Lattorfian of Europe. Vredenburg correlated the Singu mollusca with the Upper Nari and the equivalents of the Padaung with the Lower Nari. If this is true then *L. elephantina* appears earlier in Burma than elsewhere.

In the East Indies *Camerina intermedia* characterizes the stages "c" and "d." *Eulepidina papuaensis* Chapman appears in beds assigned to stage "d" by Leupold and van der Vlerk (1931). At its type locality, the Bootless Inlet limestone of Port Moresby,

Papua (Chapman 1914, and also in: Wyllie 1930, vol. 4) *E. papuaensis* occurs together with *C. intermedia* so that these beds must be considered as Oligocene. The occurrence of *Spiroclypeus* in the same beds is doubtful. The stratigraphic relation of the Bootless Inlet limestone to the Eocene Port Moresby beds is uncertain. *E. dilatata* has not been found together with nummulites in the East Indies. Douvillé (1905, p. 435) recognized in material from Borneo a distinction between older beds with reticulate nummulites without *Eulepidina* and younger beds (Stampian) with the same nummulites and "*Eulepidina* of the *formosa* group". Leupold and van der Vlerk (1931) and Koolhoven (1933) confirmed this subdivision. Their evidence was not accepted by Tan Sin Hok who however does not deny that the first appearance of the subgenus *Eulepidina* distinguishes the later (Rupelian) from the earlier (Lattorfian) stage.

This raises the question of the representation of the Upper Oligocene (Chattian) in the East Indies, since the Rupelian is generally considered as Middle Oligocene (Vaughan 1924, pp. 712f.). A number of authors let the Aquitanian follow immediately after the Rupelian but this does not seem to be the correct procedure. Although no complete marine sequences are known in the type areas, detailed work elsewhere in Europe has shown that "type" Aquitanian and "type" Chattian do not overlap.

The highest beds with reticulate nummulites are invariably followed in complete sections in the East Indies by beds with *Eulepidina, Spiroclypeus, Miogypsinoides* and other larger foraminifera. This is stage "e" of van der Vlerk and Umbgrove. The top of this stage was recognized by H. Douvillé, Gerth and Tan as the top of the Aquitanian. The main criterion used for defining the base of stage "e" is the same as that applied by Vredenburg for the distinction between Lower Nari (Rupelian) and Upper Nari (Chattian). Tan (1939*a*) quotes the following European species from the "e-stage": *Lepidocyclina elephantina* Munier-Chalmas, *L. dilatata* (Michelotti), *L. marginata* Michelotti, *Miogypsinoides complanata* (Schlumberger), *Heterostegina assilinoides* Blankenhorn. Most of these are known from Upper Oligocene and Lower Miocene (Chattian-Aquitanian). Accordingly, the stage "e" is placed in Chattian and Aquitanian in the European scale (Tan, 1932, Table IV.). Umbgrove has in a number of his publications insisted on the occurrence of important transgressions in a higher horizon of stage "e". Tan, in his critical reviews, does not find sufficiently clear evidence for the recognition of any of van der Vlerk's five "zones" of this stage, and therefore the horizons of transgressions cannot be as accurately fixed within the stage as Umbgrove maintained. Umbgrove's observations agree however in a general way with

Lepper's statement of overlap by the Pyawbwe clay (Aquitanian) and an important unconformity in the uppermost parts of the Oligocene in Burma (quoted by Glegg, 1938).

No molluscan assemblages of "e-age" have been described from the East Indies and direct correlation with Burma is therefore impossible. The Rembang fauna, believed at the time of Vredenburg's work to be Aquitanian, has since been found to be younger and to occur together with typical post-Aquitanian foraminifera.

In the Cape Range limestones of North-western Australia (F. Chapman 1927, I. Crespin 1938) different assemblages of larger foraminifera, mainly *Eulepidina*-species, corresponding to the "e-stage" fauna of the East Indies, have been found. Oligocene is known from New Guinea and New Ireland (Schubert 1911) but has not been reported from the New Hebrides or New Caledonia.

Tan Sin Hok (1939*a*, p. IV. 100) has warned us that only the presence of genuine reticulate nummulites is stratigraphically important, that their absence may be caused by ecologic conditions and that "in some cases the discrimination of a 'genuine' *Camerina* from *Operculinoides* Hanzawa is very difficult, the latter being *Camerina*-like operculines which also occur in the Indo-Pacific Neogene." Such forms are still creating much confusion in stratigraphy and a revision of the group is urgently needed. It includes *Nummulites niasi H.* Verbeek (= *N. variolaria* Brady 1875, non Sowerby, see R. D. M. Verbeek and R. Fennema, Descr. géol. de Java et Madoura, 1896, vol. 2, p. 1157), *N. makullaensis* Carter (Vredenburg 1906) from the Gaj; *N. doengbroeboesi* Verbeek (Schubert 1911), and possibly other species.

### 3 Correlation of Miocene Deposits Containing Larger Foraminifera.

In some recent classifications of the Tertiary of the East Indies the use of the term "Miocene" is still avoided It is admitted that it is at present difficult, if not impossible, to define satisfactorily both the upper and the lower boundaries of this series. It would be easy and perhaps convenient to regard all post-nummulitic *Lepidocyclina*-bearing beds as Miocene but this is not in agreement with the use of the term elsewhere and with its original definition and the typical sequence of rocks covered by it. There is some difference of opinion about the position of the Aquitanian. This, in the writer's opinion, is a purely arbitrary matter to be settled by agreement and not by investigation. The majority of authors now include it in the Miocene. If we accept this view then the lower boundary of

this series in the East Indies is not, at present, biostratigraphically definable. A similar question arises concerning the top of the Miocene. If the Pontian is regarded as uppermost Miocene then all pre-Cheribonian Neogene deposits are Miocene as the Cheribonian includes, by definition, beds containing the earliest post-Pontian fauna of vertebrates. If it is possible, as it appears to be, to distinguish a "g-stage" from the Cheribonian, then this "g-stage" is Miocene under the first of the two alternative delimitations of the Series. If, however, the Pontian is not included in the Miocene then the top of the Miocene is at present not definable.

That the problem is a general one is shown by a statement recently made by G. E. Pilgrim (1940, p. 9):

> "The numerous stages or sub-stages into which I have divided the geological succession does not imply that the correlation makes any pretence at being more than approximate, but have been used partly because that is the only means by which I can take account of the large number of American faunas and partly because the system names Miocene, Pliocene and Pleistocene have at present no meaning since they have not been employed by every writer in the same sense."

Notwithstanding these difficulties, a certain part of the East Indian Tertiary sequence is definitely Miocene. This is Tan Sin Hok's "Lower and Upper Middle Neogene", Umbgrove and van der Vlerk's "f-stage", and Oostingh's Rembangian and Preangerian. These latter names appear to be well suited for general use in the Indo-Pacific Region. The Rembangian is tentatively correlated with the Burdigalian and the Preangerian with the Vindobonian (Helvetian-Tortonian) of Europe. Definite evidence, however, is available only for the correlation of the base of the Burdigalian with the base of the Rembangian, the rest being conjectural as long as no further palaeontological evidence is found. In the light of new stratigraphic and micropalaeontological data earlier inter-regional correlations based on mollusca cannot be considered as satisfactory.

Vredenburg (1921*a*, p. 328) and Martin (1931, p. 7) correlated as follows:—

| | |
|---|---|
| Younger Miocene | Odeng beds—Talar—(Sarmatian-) Pontian.<br>Tjilanang beds—Vindobonian. |
| Older Miocene | Njalindoeng beds—Pyalo—U.Gaj—Burdigalian.<br>Rembang beds—Kama—L.Gaj—Aquitanian.<br>Progo beds (not correlated). |

Gerth (1929, p. 595) has shown that the foraminiferal fauna of the Rembang beds is definitely post-Aquitanian (probably Burdigalian) and that the Progo beds are not greatly different in

age. Van der Vlerk (1924) found that in both Njalindoeng and Tjilanang beds only *Trybliolepidina* represents the lepidocyclines and Gerth (l.c., p. 596) concluded that both are "Younger Miocene", younger than the Rembang beds and possibly Vindobonian. According to the same author the Odeng beds are equivalents of the Tjilanang beds. The absence of pre-Rembangian molluscan faunas in Java and the incomplete knowledge of Vindobonian molluscan assemblages from India add to the difficulty and uncertainty of molluscan correlation.

The beds containing the Progo and Rembang molluscan faunas and the "$f_{1-2}$" assemblage of larger foraminifera have been named Rembangian by Oostingh. This stage is characterized, according to Tan Sin Hok (1939*a*, p. IV. 99) by *Katacycloclypeus*, *Miogypsina bifida* L. Rutten, *M. polymorpha* L. Rutten, *M. musperi* Tan, *Alveolinella* of the *bontangensis*-type (= *Flosculinella*), *Lepidocyclina angulosa* Provale, *L. inflata* Provale, and some other lepidocyclines.

Beds with this foraminiferal fauna are followed in numerous sections examined in East Borneo, Java, Sumatra, and New Guinea by beds containing a younger Miocene molluscan fauna, and instead of the foraminifera mentioned above, a younger assemblage with *Lepidocyclina* (*Trybliolepidina*) *rutteni* van der Vlerk, *L.* (*T.*) *orientalis* van der Vlerk, some *Miogypsina*, and *Alveolinella* of the *quoyi* type. They were named "Preanguerien" (here adapted to "Preangerian" according to English spelling) by Oostingh. Tan (l.c.) quotes also *Cyclolepidina* (*recte Multilepidina*) *suvaensis* Whipple as typical for this stage and claims to have found it in Java in the highest *Lepidocyclina*-bearing beds. At its type locality, in the Suva formation of Fiji and in Rembang (Java), the species occurs together with *Katacycloclypeus annulatus*, evidently in beds of Rembangian age.

No distinctive larger foraminifera are found in post-Preangerian beds, reports of *Lepidocyclina* and *Miogypsina* being based either on incorrect assumption of Pliocene age for rocks underlying Pleistocene raised reefs (Tan 1936*a*, p. IV. 85), on unconfirmed determinations, uncertain stratigraphic data, or derived specimens from older beds.

The correlation of *Lepidocyclina*-bearing rocks throughout the Indo-Pacific Region presents little difficulty. The Cape Range limestones of North-western Australia (Crespin 1938) contain not only "e-stage" assemblages but also a fauna with *Flosculinella bontangensis* and *Austrotrillina* which can be considered as Rembangian. The *Lepidocyclina*-bearing rocks of the north coast of New Guinea were described as "Conglomerat-zone" by Zwierzycki (1921, 1927) and as Aitape series by Nason-Jones (in: Wyllie, 1930). Some part of Zwierzycki's "*Globigerina*-

zone" contains *Lepidocyclina* and is probably Preangerian. *Lepidocyclina*-limestones have repeatedly been reported in situ in the high mountains of the Main Range of New Guinea, including Mt. Carstenz where the "e-stage" fauna occurs, the upper Lorentz River (Terpstra 1939), the upper Digoel River (van Bemmelen 1940) where "e-stage" limestones are followed by a predominantly arenaceous and argillaceous stage tentatively considered as Burdigalian, and the upper Fly River (e-stage, Crespin 1938*b*) In samples from New Ireland Schubert (1911) found *Lepidocyclina* and *Miogypsina*. A soft *Globigerina*-marl with *Miogypsina lagamensis* and *M. epigona* was incorrectly assigned by him to the Pliocene. In the Solomon Islands the Orovavi limestone of Bougainville with "e-stage" foraminifera described by Mawson and Chapman (1935) is the oldest known formation. The folded tuffs and foraminiferal marls observed by Guppy (1887) on a number of islands of the Solomon group and considered by him as "Recent", probably represent the younger Tertiary stages. From the New Hebrides (Santo and Malekula) F. Chapman (1905, 1907) described *Lepidocyclina*-limestones which were later named Laleppe formation by Mawson and Chapman (1 c.). Chapman figured foraminifera closely resembling *Lepidocyclina ferreroi* Provale and *L. inflata* Provale, *L. cf. martini* Schlumberger, as well as *Alveolinella cucumoides* Chapman representing the *bontangensis*-group. The Laleppe formation is evidently Rembangian

## 4. Correlation of Miocene and Pliocene Deposits not containing Distinctive Larger Foraminifera.

### The Stage "g".

To van der Vlerk's stages "a to f", all characterized by distinctive larger foraminifera, Umbgrove (1929, reprint, p. 5) added a "stage g", specifically for the Antjam and Domaring beds of Borneo. He explained:

> "It is of frequent occurrence that beds, free from Orbitoidides and situated above the Tertiary containing *Lepidocyclina-Miogypsina* are called 'Pliocene'. But when we do that, we forget the fact that there is not yet any certainty at all, as to whether the horizon of the Tjilanang beds may be correlated with the whole of the Vindobonian. It is quite possible that it only corresponds with two or one (or even less than that) of the sub-divisions of the Vindobonian (Helvetian-Tortonian-Sarmatian); in which case a part of the Tertiary, that is younger than the beds containing Orbitoidides, must be considered as belonging to the Miocene.

In Netherlands E. Borneo (Bulungan) the Miocene beds containing *Lepidocyclina* are followed immediately by the Antjam beds and the Domaring beds (Leupold) which are designated as Tertiary-g in 'Wetenschappelijke Mededeelingen No. 9' in which the Anthozoa of this horizon have also been described. It can serve no purpose to carry on the classification by letter any further as long as there are no data for fixing the boundaries and for ascertaining which organisms are distinctive".

H. Gerth (1931, p. 146) has pointed out that the Antjam beds contain two species of corals (*Astrocoenia minutissima* Gerth and *Hydrophyllia applanata* Gerth) belonging to genera unknown from the Pliocene or Recent and that these beds should therefore be considered as Miocene. Two years later, however, he transferred the first of these species to the genus *Stylophora* which is well represented in the Pliocene.

At the same time Leupold and van der Vlerk (1931) still avoiding the terms Miocene or Pliocene added a stage "h" to the letter-scale and quoted the following percentages of Recent mollusca in the higher stages:—

| | | | |
|---|---|---|---|
| h | —50–60 | per | cent |
| g | —35–45 | ,, | ,, |
| $f_3$ | —30 | ,, | ,, |
| $f_{1-2}$ | —8–20 | ,, | ,, |

The percentage of recent species of mollusca appears to be the only feature defining stage "h", apart from the multitude of formations referred to it.

Stage "g" is defined by the Antjam beds as "type sequence", and by a fauna of mollusca containing 35-45 per cent. of Recent species. This appears to be an imaginary criterium as none of the five localities from which Martin described such assemblages belongs definitely to the "g-stage". According to Gerth (1931, p. 147) the Odeng beds with 43 per cent. are stratigraphic equivalents of the Tjilanang beds with 34 per cent. and $f_3$-lepidocyclines, while the fauna from shallow wells near Batavia with 36 per cent. is according to Rutten (1927, p. 102) probably Pliocene or Pleistocene. Furthermore, there is some doubt concerning the age and stratigraphic position of the Antjam and Domaring beds. The former overlie unconformably the Koendjang beds, age and foraminifera of which are unknown, and the latter overlie with apparent unconformity the Menkrawit beds ($f_3$) and are stated to correspond to the upper part of the Kampong Baroe beds which is Pliocene (Leupold and van der Vlerk 1931, pp. 619, 621, 624).

Apart from the rather unfortunate original definition, there is other evidence for the existence of an Uppermost Miocene stage without lepidocyclines. Le Roy's recent studies on smaller

foraminifera (1941) led to the conclusion that the Sangkoelirang beds are partly younger than Preangerian and older than Cheribonian, implying the existence of an intermediate stage corresponding in stratigraphic position to Umbgrove's stage "g". In parts of Java this intermediate stage is represented by unfossiliferous deposits, largely of volcanic origin (Genteng beds of West Java, Koembang beds of Central Java) which are followed by Lower Pliocene (Cheribonian). In Eastern Java the *Globigerina*-marls of the Lower Kalibeng beds (Duyfjes 1938) follow unconformably above the Rembang beds and are overlain by Pliocene Upper Kalibeng beds and Pleistocene Poentjangan and Kaboeh beds. A fauna of smaller foraminifera described by Koch (1923) from Kabu (Kaboeh) was apparently taken from the Lower Kalibeng beds. Koch remarks that in the definitely Pliocene fauna from the Fufa beds of Ceram (Fischer 1921, 1927) only very few species are extinct and that this fauna, therefore, must be younger. Most of the extinct species found at Kabu occur also in the Kar Nicobar fauna which Koch considered as Pliocene. He determined the age of the Kabu fauna as lowest Pliocene or Upper Miocene. Two "index species" are mentioned, *Uvigerina javana* Koch and a "*Globigerina sp.*" This was later named *G. kochi* Caudri (1934) but should be placed in *Sphaeroidinella*. Neither of these species has subsequently been found in definite Pliocene. Van Es (1931) assigns these *Globigerina*-marls from Kabu to the Uppermost Miocene, "g-stage". Duyfjes considers "the greater part of the Kalibeng beds" as Pliocene but appears to be prepared to admit Uppermost Miocene age of their lowest part. A fauna of smaller foraminifera described as "Miocene" by Yabe and Asano (1937) from West Java occupies a similar stratigraphic position.

There is no evidence anywhere of *Lepidocyclina* and *Miogypsina* having survived the Tortonian (possibly even Helvetian). As the vertebrate fauna proves post-Pontian age of the Cheribonian (Lower Pliocene of Java) and as it is generally assumed (Douvillé, Tan, and others) that the highest *Lepidocyclina*-bearing stage (Preangerian) corresponds to the Vindobonian (Helvetian-Tortonian), we expect to find an intermediate, or "g"-stage, of approximately Sarmatian-Pontian age.

It is admitted that more direct evidence of the existence and fauna of this stage must be awaited before it can be fully defined and named.

## Significance and Age of the Foraminiferal Deposits of Kar Nicobar and Fiji.

Larger foraminifera, although known from many lithologically different rock types, are rare in argillaceous sediments and do not usually occur in rocks containing abundant pelagic foraminifera.

Many of these *Globigerina*-marls some of which may be stratigraphic equivalents of older *Lepidocyclina*-bearing rocks in different facies, have been classified as "Mio-Pliocene" or Pliocene on account of the absence of distinctive larger foraminifera. Undoubtedly, Indo-Pacific Tertiary smaller foraminifera can be utilized for distinctions between "*Globigerina*-marls" of different age and will be found not less useful for stratigraphic purposes than larger foraminifera when more detailed descriptive work is done. It is not possible to describe here new foraminiferal assemblages, but a critical review of the distribution of the smaller foraminifera known from the Tertiary of the East Indies, numbering about 650 species, shows that several well known species are restricted to Miocene deposits.

Until recently (Le Roy 1941), Schwager's work on Kar Nicobar (1866) and Cushman's work on Fiji (1934) were the only more or less complete descriptions of assemblages of Indo-Pacific Tertiary smaller foraminifera. Later work proved them to be representative of the whole Indo-Pacific Region. Although originally described as "Upper Neogene", they were both in recent years generally referred to the Pliocene. This classification which will be shown here to disagree with geological field data as well as with the composition of the fauna, made it impossible to distinguish between Miocene and Pliocene assemblages of smaller foraminifera.

Samples containing the Kar Nicobar fauna were taken by Hochstetter from some 20-30 feet of folded argillaceous rocks with sandstone bands overlain by young raised reef limestones. The argillaceous rocks of the Nicobar Islands were later included by Oldham (1885) in the Achipelago series. Tipper (1911) placed it in the Miocene. E. R. Gee (1926) found locally in Ritchie's Archipelago from which Oldham's stratigraphic term was derived, a late Tertiary, Pliocene or Pleistocene sequence of very loosely consolidated shelly mudstones containing numerous mollusca and occasional corals and echinoids, and a Miocene series of grey and greenish clays, argillaceous sandstones, white shelly limestone, and occasional conglomerates, representing the Archipelago series of Oldham, which is more affected by earth movements than the upper almost horizontal beds. This group includes foraminiferal limestones with *Lepidocyclina,* overlying clays on Wilson Island. While Tipper considered the Miocene Archipelago clays as younger than limestones with *Lepidocyclina cf. sumatrensis,* Gee found that similar limestones are interbedded in the Archipelago series. All geologists agree that the clays and sandstones of the Nicobar Islands belong to the Archipelago series which is Miocene, and is closely connected with *Lepidocyclina*-bearing rocks.

The foraminiferal assemblage described by Schwager contains 104 species, 34 of which occur in the Recent Pacific fauna. The percentage of Recent species is therefore 33. Forty-eight species

are also known from the Suva formation of Fiji; 53 species are recorded from other localities in the East Indies; 30 of these are extinct Of this number 14 were found in the Bulongan fauna (Koch, 1926) with *Lepidocyclina* (stages e–f), 9 in the Uppermost Miocene (stage g), and 7 in Upper Miocene and Pliocene The fauna shows relations only to Miocene assemblages of smaller foraminifera. The conclusion of a Miocene age of the Kar Nicobar fauna agrees with the revised age of the closely related Fiji fauna.

The age of the Suva formation of Fiji was recently discussed by H. Ladd (1934, p. 99 ff.) who tried to reconcile contradictory palaeontological data with each other and with the field evidence. The Suva formation is undoubtedly younger than the Viti limestone with *Lepidocyclina (Eulepidina) formosa* Schlumberger (e-stage). The majority of the earlier authors considered the larger fossils of the Suva formation as Miocene or early Pliocene. Among the "small and incomplete" molluscan fauna Ladd distinguished an older assemblage with 9·5 per cent. Recent species and a younger fauna with 21 per cent. Recent species. He found a number of species which had been recorded from Miocene only and accordingly placed the Suva formation in "Lower to Upper Miocene" (f and g stages) but admits, on the evidence of smaller foraminifera and corals the possibility of Pliocene age of part of the Suva formation.

In the light of later data Whipple's determination of the age of the Suva larger foraminifera as "e-stage" which according to Ladd disagreed with the balance of stratigraphic evidence, has to be modified. In the Suva area, in close proximity to the type section, the following assemblage of larger foraminifera was found: *Katacycloclypeus annulatus* (Martin), *Cycloclypeus neglectus* Martin, *Multilepidina suvaensis* (Whipple) (= *M. luxurians* Tobler sp.?), *Lepidocyclina* (*Trybliolepidina*) *aff. radiata* Martin, and several microspheric lepidocyclines described as *L. dilatata* (Michelotti), *L. dilatata var. laddi* Whipple (= *subradiata* H. Douvillé?), and *L. papulifera* H. Douvillé. This is a Rembangian assemblage (see Caudri 1939, locality 27*b* and others). The occurrence of a microspheric form described as *L. dilatata* is unimportant while the occurrence of *Katacycloclypeus* and *Multilepidina* which are unknown in the "e-stage", is decisive.

Ladd states (l.c., p. 95): "Cushman identified 95 species of smaller foraminifera from Station 371 which lies only 2 miles from the type section on Walu Bay and at about the same elevation. The same marls outcrop at many points between the two stations, and as all of them are horizontal it is certain that the marls of Station 371 are very close stratigraphically to the type section of the Suva formation."

In Cushman's publication (1934) 118 species of smaller foraminifera are described and most of them are figured. Approximately 64 species or 54 per cent. are Recent. Forty-eight

species occur also at Kar Nicobar. Of 28 extinct species also known from other localities not more than three have been recorded from both Miocene and Pliocene deposits, the others are known from Miocene. Of these, 10 come from beds originally determined as Miocene, 3 from Kabu, later assigned to the Upper Miocene, and 24 are known from Kar Nicobar.

The distribution of extinct species occurring in the Fiji fauna indicates Miocene age. The percentage of recent species is much smaller than in definitely Pliocene assemblages (88 and 94 per cent. in the Fufa beds of Ceram, 75 to 89 per cent. in Java) and lies between that of the Bulongan fauna (48 per cent., "e" or "f" stage) and that of the Kabu fauna (61 per cent., probably "g-stage"). The fauna of smaller foraminifera of the Suva formation of Fiji is therefore not Pliocene but Miocene and apparently contemporaneous with the Rembangian assemblage of larger foraminifera found in close proximity to the type section.

STRATIGRAPHIC POSITION.

The stratigraphic position of important known assemblages of smaller foraminifera from the Indo-Pacific Region is graphically shown in Table 1.

TABLE 1.

| Series. | Stages. | Sumatra and Mentawei Islands. | Java. | Ceram, Borneo | Fiji. | Per cent. Recent Species |
|---|---|---|---|---|---|---|
| — — — | Bantamian | — | Bodjong* LR<br>West Java* YA | Ceram* F, K | | |
| Pliocene | Sondian | — | Sonde* BV | — — — — | — | >70 |
| | Cheribonian | — | | — | | |
| | "g" | "Fluvio-brackish" LR<br>Siberoet LR | Kabu K<br>West Java YA | Sangkoelirang LR ↓ | — | 60–70 |
| Miocene | Preangerian | "Transitional"* LR<br>Kar Nicobar S<br>Telisa* LR ↓ | — | ? | Suva C | <60 |
| | Rembangian | | — | Bulongan* K ↓ | | |
| | "e" | —?— | — | —?— | — | ? |

(Explanation of abbreviations and symbols used.
Authors' names—
LR—L. W. Le Roy 1939, 1941
YA—H. Yabe and K. Asano 1937.
BV—L. Boomgart and J. Vroman, 1936.
F—P. Fischer 1921, 1927.
K—R. Koch, 1923, 1925, 1926.
C—J. A. Cushman 1931, 1934.
S—C. Schwager 1865.
Arrows indicate that the fauna or part of it may be older.
Assemblages shown as extending over more than one stage may but do not necessarily represent the whole of these stages. * designates age determinations suggested by the authors named).

The figures for percentages of Recent species included in Table 1 are approximate. They are based on the following results of counts and calculations which owing to limitations of space cannot be fully discussed here:—

| | |
|---|---|
| STAGES "e–f": | |
| Telisa, "Transitional" (Le Roy) | 24 per cent. |
| Kar Nicobar (Schwager) | 30 „ „ |
| Bulongan (Koch) | 48 „ „ |
| Fiji (Cushman) | 54 „ „ |
| STAGE "g": | |
| Sangkoelirang (Le Roy) | 60 „ „ |
| Kabu (Koch) | 61 „ „ |
| West Java (Yabe and Asano) | 65 „ „ |
| Siberoet (Le Roy) | 69 „ „ |
| PLIOCENE: | |
| Bodjong (Le Roy) | 73 „ „ |
| West Java (Yabe and Asano) | 86 „ „ |
| Ceram (Koch) | 88 „ „ |
| Sondé (Boomgart and Vroman) (includes Pleistocene) | 89 „ „ |
| Ceram (Fischer) | 94 „ „ |

It is not correct to assume that within the limits of the stages the fauna with the lower percentage is necessarily older. The transition from Miocene to Pliocene is evidently accompanied by a more rapid and therefore clearly expressed change in the composition of the foraminiferal fauna which definitely advanced the previously and subsequently fluctuating ratio. This gives an approximate indication of the age of an assemblage of foraminifera equal in value to the different and much lower percentages of Recent molluscan species.

## MIOCENE INDEX FORAMINIFERA.

Of greater importance for stratigraphic correlation are index species of known, restricted, vertical range. The ranges of certain important larger foraminifera are shown on the accompanying chart, according to the latest available data. The following tentative list of selected species of smaller foraminifera, all recorded from more than one locality, is based entirely on published data arranged according to the chart (p. 67). These data do not enable us yet to distinguish index species for the different stages of Miocene and Pliocene among the smaller foraminifera but they prove that a considerable number of important Miocene species have never been found in younger deposits. Some of them are placed on record in the following list:—

*Austrotrillina howchini* (Schlumberger).
*Bifarina crenulata* Le Roy.
*Bulimina microlongistriata* Le Roy.
*Cassidulina murrhyna* (Schwager).
*Cassidulina bicornis* (H. B. Brady).
*Chrysalogonium polystoma* (Schwager).
*Cibicides fijiensis* (Cushman).

*Cibicides dorsopustulosus* Le Roy.
*Clavulinoides szaboi* (Hantken).
*Dentalina stimulea* (Schwager).
*Dorothia subrotundata* (Schwager).
*Eggerella? subovalis* (Schwager).
*Eponides multiseptatus* (Koch).
*Gaudryina solida* Schwager.
*Karreriella siphonella* (Reuss).
*Lagena castrensis* Schwager.
*Lagena schwageriana* Cushman.
*Listerella victoriensis* Cushman.
*Marginulina subtrigona* Schwager.
*Marginulina subbullata* Hantken.
*Nodosaria arundinea* Schwager.
,, *crassitesta* Schwager.
,, *equisetiformis* Schwager.
,, *hochstetteri* Schwager *et var.*
,, *inconstans* Schwager.
,, *koina* Schwager.
,, *skobina* Schwager.
*Pulvinulinella bengalensis* (Schwager).
*Pyrulina labiata* (Schwager).
*Robulus javanus* (Koch) *et var.*
*Siphonina australis* Cushman.
*Siphonodosaria adolphina* (d'Orbigny).
,, *maculata* (Schwager).
,, *insolita* (Schwager).
,, *setosa* (Schwager).
*Sphaeroidinella kochi* (Caudri).
,, *seminulina* (Schwager).
*Textularia solita* (Schwager).
*Uvigerina gemmaeformis* Schwager.
,, *hispida* Schwager.
,, *javana* Koch.
*Vaginulina perprocera* (Schwager).
*Vaginulinopsis gradata* Thalmann.
*Vulvulina nicobarensis* (Schwager).

## 5. Further Problems of Tertiary Correlation.

Much further work on stratigraphy and palaeontology of the Pacific Islands is required before the stratigraphic classification of the Tertiary sediments developed in the key areas of the East Indies can be extended over the whole Indo-Pacific Region. The main problems can be outlined as follows:—

(1) Correlation of the two post-Aquitanian Miocene stages (Rembangian and Preangerian) characterized in Java and elsewhere by distinctive species of mollusca, larger and smaller foraminifera.

(2) Confirmation of the existence of the Uppermost Miocene stage "g".

(3) Correlation of the Cheribonian, Sondian, and younger molluscan faunas of Java which are known to represent the European Pliocene and Pleistocene on account of their relations to vertebrate-bearing beds, with the molluscan faunas of the same age from New Guinea and other islands

(4) Study of the smaller foraminifera of the "Younger Tertiary" deposits reported from many islands between New Guinea and Tonga, with special reference to stratigraphic ranges, recognition of species restricted to the Miocene, and the gradual increase in the number of Recent species in younger deposits.

Faunal relations between the surprisingly uniform Tertiary of the Indo-Pacific Region and that of South-eastern Australia and New Zealand are limited and are either created by "eurythermic" species which were able to cross the boundary of the tropical belt or by short-lived climatic or ecologic changes creating a suitable environment for warm-water species and genera. In the Tertiary of Victoria the Batesfordian containing a group of *Lepidocyclines* as well as *Austrotrillina* and perhaps some other Indo-Pacific smaller foraminifera forms a short-lived link with the Indo-Pacific Region. I. Crespin (1941, p. 254) concludes "The Middle Miocene age is supported by a close study of the *Lepidocyclinae* (so characteristic of this stage) and *Cycloclypeus* and their relationships with Indo-Pacific assemblages".

In New Zealand "*Miogypsina* appears for the first time, and is abundant in, and limited to, the Hutchinsonian. This also applies to our various species of *Lepidocyclina*, which are all Nephrolepidine". (Finlay and Marwick 1940, p. 94.) Mr. W. J. Parr drew the writer's attention to the fact that F. Chapman had described *Lepidocyclina (Eulepidina) dilatata* (Michelotti) from Hokianga South Head, North Auckland, McKay's loc. 733 (F. Chapman, The Cretaceous and Tertiary Foraminifera of New Zealand. *N.Z. Geol. Survey, Pal. Bull.* No. 11, 1926, p. 93, pl. 20, f. 1) Material from this locality which was kindly made available by Mr. Parr from his rich collections, proves beyond doubt that a typical *Eulepidina* occurs in New Zealand, together with an undescribed species of *Nephrolepidina*, and also, according to F. Chapman (l.c.) together with *Miogypsina irregularis* (Michelotti). The species of *Nephrolepidina* mentioned by Finlay and Marwick have not been described or figured from New Zealand. These authors place the Hutchinsonian in the "Lower Miocene".

Specific features and generic ranges of the majority of the Indo-Pacific larger foraminifera differ considerably from species and distribution of the same useful group of fossils in tropical

Central America. Owing, perhaps, to the vast distance in space or to the absence of Tertiary land bridges across the Pacific Ocean which would have provided suitable shallow-water environment, faunal links are extremely rare. In this respect the smaller foraminifera show very promising signs of inter-continental relations. To any student of the Indo-Pacific Miocene smaller foraminifera, the Bowden fauna of Jamaica or the fauna of the Port-au-Prince beds of Haiti recently described by Coryell and Rivero (Journ. of Paleont., vol. 14, No. 1, 1940), appear strikingly familiar. The uncertain stratigraphic position of Indo-Pacific Tertiary foraminiferal assemblages has hitherto prevented authors from attempting trans-Pacific faunal correlations. This work remains outside the scope of the present review.

## III. Notes on the Geological History of the Indo-Pacific Region.

1. The relations of the Jurassic of New Guinea, North-western Australia, New Caledonia, and New Zealand suggest the existence of a Jurassic Circum-Australian geosyncline connected with the Timor-East Celebes geosyncline and linked with the Tethyan sea in the Himalaya.

2. While there are indications of a marine transition from Jurassic to Lower Cretaceous in the Timor-East Celebes geosyncline, pre-Aptian marine Cretaceous deposits appear to be absent in Australia and New Guinea. A similar but still ill-defined break is found between Jurassic and Cretaceous in New Caledonia. The time of this break corresponds to the important epi-Jurassic (Pacific or Young Kimmeric) phase of folding in New Zealand and elsewhere.

The time following immediately after the close of the Jurassic Period, shows throughout the area of the Jurassic Circum-Australian geosyncline clear signs of what Sir T. W. E. David, referring to Australia, called a "vast geographical change" (1932, p. 171). Aptian, Albian, Cenomanian, and possibly also Barremian are locally transgressive on Jurassic, Triassic, and older beds. The geographical continuity of the Tethyan fauna is temporarily interrupted by ecological (climatic?) and possibly also topographic barriers.

3. The range of *Globotruncana* rocks throughout the area shows that in the Senonian Epoch the Mediterranean (Tethyan) affinities in the Circum-Australian zone are restored, at least as far as planktonic foraminifera are concerned. The typically Mediterranean Senonian larger foraminifera (*Orbitoides*, etc.) are not yet known beyond Northern India and Burma, and there are certain specifically Pacific features in the Upper Cretaceous molluscan fauna.

4. Throughout the region east of Burma no fossiliferous deposits of Uppermost Cretaceous (Danian) or Lowest Tertiary age are known. The Eocene rest generally unconformably on older rocks (Umbgrove 1938, Table 6).

The late Cretaceous Laramic orogeny must have finally broken the continuity of Tethyan faunal relations. Epi-Cretaceous folding movements are reported to be widespread throughout the Timor-East Celebes geosyncline and extended probably to New Guinea where conditions before the end of the Cretaceous Period reverted to geosynclinal, and to New Caledonia. The Westralian part of the former Circum-Australian geosyncline shows according to Raggatt (1936) no signs of movement after the deposition of a typically epicontinental series of Upper Cretaceous sediments.

5. The difference between the western and eastern parts of the Circum-Australian area of Palaeogene deposition is very marked.

Umbgrove (1938, p. 34) states that in the East Indies "all marine Palaeogene sediments have been deposited in shallow epicontinental seas (neritic and littoral). The strong relief as we know it at this moment—the many deep sea basins—originated much later".

In south-eastern New Guinea and New Caledonia the Eocene is rich in siliceous rocks, partly containing abundant radiolaria, and is affected by basic intrusions. Although the presence of intercalated beds with abundant nummulites and other larger foraminifera makes an abyssal origin of the siliceous rocks improbable, their geosynclinal character can hardly be denied in view of many examples of similar rocks formed in pre-Tertiary geosynclines. More than purely ecological differences between the two areas appear to be expressed in this inequality of Palaeogene deposition. It is probably connected with the important "diversity of structural controls" between the Australian-Asiatic and the Australian-Pacific boundary zones, which was first postulated by W. N. Benson (1924, p. 133). If the existence of a similar development of siliceous rocks and basic intrusions in late Cretaceous and early Palaeogene time in the Arakan Yoma-Andaman arc is confined, then these occurrences would point to a remarkable parallel between the border zones of the Indian Ocean and of the Pacific.

6. During the Palaeogene and Miocene enormous thicknesses of sediments began to accumulate in some basins of gradual subsidence within the generally epicontinental and more or less stable areas. Umbgrove refers to these remarkable basins as "idiogeosynclines". North and South-east Sumatra, the central

belt of Java, and several basins in East Borneo are examples of such areas which contain the richest oil-bearing strata of the East Indies (Umbgrove 1938, pp. 39 ff., and also in: Vening Meinesz 1934, pp. 155 ff.).

Most of these idiogeosynclines began their existence later, in early Miocene time, partly in connection with a widespread transgression which Umbgrove named "Beboeloeh transgression" dating it as Upper Aquitanian ($e_5$). Other authors are only prepared to admit that transgressions occurred between Upper Oligocene and Lower Miocene. Several idiogeosynclines appear to have existed in the New Guinea area. Sedimentation in the idiogeosynclines ended generally in the Pliocene with the deposition of sediments in paralic facies (shallow water marine beds with coal and non-marine intercalations). The idiogeosynclines have been subjected generally to folding in late Pliocene and Pleistocene time.

On the north coast of New Guinea, in New Ireland, and in the Solomon Islands some of the widespread *Globigerina*-sediments belong to the Pliocene and Pleistocene. Locally even very young chalky radiolarian rocks are known (Tan Sin Hok 1926). This pelagic fauna and sedimentation indicates free connection with the open sea along the outer Pacific border rather than young submergence to abyssal or bathyal depth of these areas which are at present definitely rising.

7. The old Timor-East Celebes geosyncline, while not known to differ from adjoining areas in Tertiary sedimentary history, is characterized by strong intra-Miocene folding. According to the Dutch geologists a belt of less intensive folding follows the West coast of Sumatra and the South coast of Java and extends further eastwards.

8. Areas of more or less undisturbed Tertiary are found on the Sahul shelf and in North Celebes. Sundaland, including the east coast of Sumatra, the Malay Peninsula, and Western and Central Borneo, had become stabilized and was in Tertiary time above sea level. Plio-Pleistocene folding and uplift joined the area of the surrounding idiogeosynclines to that of Sundaland the Pleistocene outline of which is believed to be marked by a subsequently submerged shelf.

On the Sahul shelf and in North-western Australia mainly coralline and foraminiferal limestones were deposited in Tertiary time. In the former area the same type of sedimentation appears to continue to the present time while in the latter late Miocene or Pliocene folding or warping created wide folds with low-dipping flanks (Raggatt 1936, p. 169).

9. Data on the geology of New Guinea and other Pacific Islands are insufficient for general statements on their Tertiary history. Umbgrove considers late Miocene folding of the Main Range of New Guinea as possible and van Bemmelen (1939) assumes a Burdigalian (Rembangian) phase of folding followed by renewed Upper Miocene-Pliocene sedimentation. There is also ample evidence of Plio-Pleistocene folding. Fiji and Tonga, belonging to a stable area beyond the Circum-Australian folded belt, were subjected to uplift commencing in Miocene time (Ladd 1934, Hoffmeister 1932).

10. Our knowledge of the important young or Recent movements in the Pacific Islands will be greatly advanced when "raised reef limestones" and foraminiferal sediments will be assigned to the various Tertiary stages which some of them undoubtedly represent, or to the Quaternary, according to their fauna. In many earlier reports they have been summarily described as Recent or Pleistocene deposits in accordance with their often misleading general appearance Recent work in the Fiji and Tonga Islands as well as Mr F. Chapman's and Miss I. Crespin's numerous contributions to the problem show the paramount importance of the results of modern biostratigraphic work in the East Indies as a base for our understanding of the whole Indo-Pacific Region.

It is hoped that the critical review presented here will contribute, by stimulating discussion of the problems outlined, to further progress.

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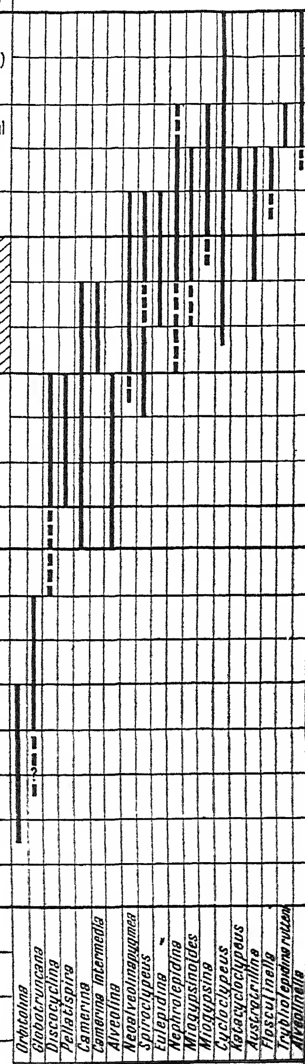
# Correlation of Marine Rocks in the Indo-Pacific Region

*Compiled by M F Glaessner 1942*

| | European Stages | India (Selected areas) | Burma | Andaman and Nicobar Islands | East Indian Archipelago Western Part | East Indian Archipelago Eastern Part | North & N. West Australia | Queensland | New Guinea | Solomon Islands | New Caledonia | New Hebrides | Viti Levu (Fiji) | Eua (Tonga) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pliocene | Gwadar; Mekran | | (Highest Tertiary beds of Andaman Islands) | × Bantamian ⊚ × Sondian ⊚ Cheribonian ⊚ | Fufa beds and × equivalents ⊚ | Yardie Creek Coralline limestone | | Brown coal zone, Fossil zone; Finsch Coast; Brown coal beds, Cape Possession & equivalents ⊚ | ? (Foraminiferal marls and tuffs) | | (? Pliocene at Malekula) | | (Coralline limestones) |
| Miocene | Pontian Sarmatian | Talar; Mekran ⊚ | Irrawaddy ⊚ | ? | × "g" | "g" | | | Globigerina zone; × ⊚ "g" | | | | | |
| Miocene | Tortonian Helvetian | | Obogon ⊚ | • × Archipelago series | • × Preangerian ⊚ | • "f3" | ? | | •(Beds with Lepidocyclina rutteni, | | | | ? | ? (Foraminiferal tuffs with Aturia) |
| Miocene | Burdigalian | Upper Gaj ⊚ | Kyaukkok (Prome, Pyalo) ⊚ | | • × Rembangian ⊚ | • "f1-2" | • | | (Lepidocyclina limestone and conglomerate) • AITAPE; •Katacycloclypeus annulatus, | ? | | • Laleppe | • × Suva | ? |
| Miocene | Aquitanian | • Lower Gaj | Pyawbwe (Kama) ⊚ | ? | • "e" | • "e" | • Cape Range Limestones | | • Spiroclypeus Eulepidina Neoalveolina) | • Orovavi limestone | | | | |
| Oligocene | Chattian | Upper • Nari | Okhmintaung (Singu) ⊚ | | | | | | | | | | • Viti | |
| Oligocene | Rupelian | Lower • Nari | • Padaung ⊚ | | • "d" | • "d" | ? | | •(Beds with Camerina intermedia); Bootless • Inlet Limestone | | | | | |
| Oligocene | Lattorfian | | Shwezettaw | | • "c" | • "c" | | | ? | | | | | |
| Eocene | Wemmelian 'Ledian' | Mula Pass (of Baluchistan) | • Yaw Pondaung ⊚ | ? | • "a+b" ⊚ | • "a+b" | • Giralia limestone | | (Discocyclina Alveolina Lacazina Limestones) •; Port Moresby beds • | | (Limestones marls and • cherts) | | | (Discocyclina • limestone) |
| Eocene | Lutetian | • Kirthar ⊚ | Tabyin Tilin | (Eocene of Andaman Island) | ? | ? | ? | | | | | | | |
| Eocene | Ypresian | • Laki ⊚ | Laungshe | | | | | | ? | | | | | |
| Paleoc. | Thanetian Montian | • Ranikot ⊚ | ? | ? (Equivalents of Axials) | | | | | ? | | | | | |
| Cretaceous | Danian | Niniyur | "Axials" | | | | | | | | | | | |
| Cretaceous | Senonian | Ariyalur | | | Martapoera | (Inoceramus-Radiolites marl) | (Limestone, Greensand Chalks) "Cardabia" | | (Globotruncana limestones) | | St. Vincent ? | | | |
| Cretaceous | Turonian | Trichinopoli | | | | (Globo-truncana rocks) | ? | | ? | | | | | |
| Cretaceous | Cenomanian | Utatur | | | | Upper Fatjet | Melville Island beds | | Kerabi Valley ammonite beds ? | | ? | | | |
| Cretaceous | Albian | Coral reef limestone | | | Seberuang (West Borneo) (Orbitolina rocks in Java and Sumatra) | Limestones and equivalents (No evidence of Albian, Aptian Barremian) | (Cherts & Siltstone) Cardabia beds, Winning | Tambo | Purari River limestones and sandstones | | | | | |
| Cretaceous | Aptian | Ukra Hill | | | | | | Roma | ? | | Moindou | | | |
| Cretaceous | Barremian Hauterivian | | | | | | | | | | ? Dumbea ? | | | |
| Cretaceous | Valanginian Infravalanginian | Lochambel | | | (Valanginian in Sumatra) | | ? | | ? | | ? ? | | | |
| Jurassic | Tithonian | Umla; Chidamu | | | | | | | | | La Foa | | | |
| Jurassic | Kimmeridgian | Katrol | Himalaya, Spiti shales | | | | | | (Unknown) | | | | | |
| Jurassic | Oxfordian | Kantcote; Dhosa; (Belemnite beds) | | | | | (Buchia-Belemnopsis beds of Broome) | | Buchia Belemnopsis beds | | | | | |
| Jurassic | Callovian | Chari | | | (Dogger and Malm in Borneo) | (more or less complete in geosynclinal facies) | | | (Shales with Ammonites etc.) | | | | | |
| Jurassic | Bathonian | Patcham | | | (Dogger in Sumatra) | | ? | | | | | | | |
| Jurassic | Bajocian | | | | | | (Beds with Ammonites) | | | | | | | |
| Jurassic | Lias | | | | (Lias in Borneo) | | | | | | | | | |
| | Bibliographic References → | Cotter 1938a, Holland 1926, Pilgrim 1928, Spath 1933, Vredenburg 1906, 1921, 1921a | Glegg 1938, Cotter 1938, Evans and Sansom 1941 | Gee 1926, Oldham 1885, Tipper 1911 | Le Roy 1941, Leupold and Van d Vlerk 1931, Oostingh 1938, Umbgrove 1933, 1938, Wanner 1931, Zeylmans 1939 | Caudri 1934, Fischer 1927, Leupold & Van d Vlerk 1931, Umbgrove 1935, 1938, Wanner 1931 | Crespin 1938, 1938a, Raggatt 1936, Singleton 1940, Teichert 1939, Whitehouse 1926 | David 1932, Whitehouse 1926 | Brouli 1924, Crespin 1938b, 1939, Gibb Maitland 1905, Schubert 1911, Stanley 1923, Wyllie & others 1930, Zwierzycki 1921, 1927, 1932 | Guppy 1887, Mawson and Chapman 1935, Schubert 1911 | Benson 1928, Piroutet 1927 | Chapman 1905, 1907, Mawson 1905 | Ladd 1934 | Hoffmeister 1932 |




STRATIGRAPHIC RANGES OF SOME IMPORTANT GENERA AND SPECIES OF FORAMINIFERA IN THE INDO-PACIFIC REGION.

**— EXPLANATION OF —**
**— SYMBOLS USED —**

- • Larger foraminifera } Described from
- × Smaller foraminifera } Tertiary formations
- ⊚ Larger fossils
- ⁓ Unconformities
- /// Depositional or erosional hiatus or non-marine deposition.

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[To face page 80.]

[PROC. ROY. SOC. VICTORIA, 55 (N.S.), PT. I., 1943.]

# ART. IV.—*The Geology of Bindi, Victoria.*

By A. J. GASKIN, B.Sc.

[Read 9th July, 1942; issued separately 1st May, 1943.]

## Abstract.

South of Mt. Tambo, Middle Devonian limestones unconformably overlie metamorphic schists and gneissic granite. The granite is intrusive into sandstones, presumed to be of Upper Ordovician age. A flow of rhyo-dacite overlies the schist complex, and is conformably overlain by the Middle Devonian limestones. Petrographically the flow is identical with flows at Buchan, classed with the "Snowy River Porphyries".

The structure of the limestones is a westward-dipping monocline of variable dip, which has been faulted into its present position, with the development of an extensive shear zone along its north-eastern boundary. Upper Devonian conglomerates overlie the limestones, with no evidence of a major angular unconformity. The conglomerates have been involved in the shearing processes, with the limestones.

INTRODUCTION.
PHYSIOGRAPHY.
METAMORPHIC COMPLEX.
  Schists and Gneisses of the Omeo Series.
  Upper Ordovician.
ACID EXTRUSIVES.
BINDI LIMESTONES.
  Normal Limestones.
  Marmorized Limestones.
MOUNT TAMBO SERIES.
HYPABYSSAL INTRUSIONS.
  Pegmatite.
  Diabase.
  Monchiquite.
PETROGRAPHIC DESCRIPTIONS.
AGE RELATIONS AND TECTONICS.
SUMMARY.
REFERENCES.

## Introduction.

The area dealt with in this paper comprises the major portion of the Parish of Bindi, together with portions of the surrounding parishes of Moonip, Eucambene, Terlite-Munjie and Ensay. The approximate boundaries are: to the north and west, the Tambo River; to the east, the Nuniyong Plateau; and to the south, Junction Creek and the ranges west of Mount Bindi. Access to the parish is gained by a single track from Tongio, which is on the Omeo Highway, about 60 miles north of Bairnsdale.

The earliest published reference to the area is that of A. R. C. Selwyn (1866) in which he suggests that the Bindi limestones overlie the "plant-bearing sandstones and conglomerates" of

Mount Tambo The age of the limestones was shortly afterwards established as Middle Devonian by McCoy, who in 1876 listed the fossils then known.

A. W. Howitt, in his classic paper on the Devonian rocks of North Gippsland, produced evidence to show that the limestones underlie the Mount Tambo beds and overlie the quartz porphyry and gneissic granite. He also showed that the Tambo beds were not metamorphosed to the same extent as the Upper Ordovician, attributing the changes produced in the Tambo beds near their contact with the granite, to percolation of siliceous solutions along this plane of weakness. Although he found westerly dips to prevail throughout the limestones, he postulated a synclinal attitude for these beds, regarding them as having been deposited on a granite-quartz porphyry basement complex, and subsequently undergoing open folding and erosion. Their denuded remnants were then covered by the Tambo beds.

J. Stirling (1884) noted the occurrence of marble at Bindi, and assigned its origin to the contact metamorphic effect produced in the Middle Devonian limestones by the quartz porphyry, which he considered to be intrusive. In the bed of Old Hut Creek, he recorded "protruding blocks of purplish and brownish conglomerate, the dip being rather obscure." Since these blocks were at a lower level than the limestone outcrops, he considered that they, and the analogous Tambo beds, underlay the Middle Devonian. It can now be shown, however, that this apparent discrepancy is due to faulting. In a later paper (1886) he developed his idea, mapping a coarse reddish conglomerate as extending underneath the Bindi limestones and outcropping along most of their eastern boundary. During 1886, however, he worked in collaboration with Howitt, and they concluded that the porphyry was not intrusive, the marmorisation being due to the pressure exerted on the limestone by a once considerable thickness of overlying rocks. Howitt also showed that the evidence given by Stirling regarding the Lower Devonian age of the Mount Tambo beds was inconclusive. In a report on a survey of the parish of Bindi, O. A. L. Whitelaw lists and briefly describes the various formations His summary of the history of the area in no way differs from that given by Howitt.

## Physiography.

The Bindi limestones lie in a topographic basin, bounded on all sides by steep ridges of harder rocks. The limestones have been let down into their present position by faulting, and, owing to their greater susceptibility to erosion, the area in which they occur has been reduced in level below that of the surrounding ranges.

In the northern part of the area, the Tambo River flows westward, skirting the edges of the massive conglomerates and sandstones of Mount Tambo, and forming the northern boundary of the parish of Bindi. Just before reaching the granite, the river swings in a right-angle bend, and flows southwards through a zone of fractured gneissic rock which extends parallel to the old fault line determining the western boundary of the limestone. In this part of its course, the river is joined by three tributaries—Old Paddock Creek, Bindi Creek and Junction Creek. Old Paddock Creek drains the acid lava flows covering the eastern portion of the parish of Bindi and the lower ridges of the Nuniyong Plateau. In its upper course, this creek flows north-west, following the strike of the limestones along their eastern escarpment, and then cuts through the limestone escarpment to flow westward through less resistant shaly limestones. Bindi Creek flows north-west through the centre of the area, draining the dip slopes of the limestones. Junction Creek marks the southern boundary of the basin. It rises on the western slopes of Mount Bindi and flows westward over the metamorphic rocks of this part of the area.

The greater part of the limestone is covered with a thick mantle of reddish soil, and is almost treeless, the rounded grassy slopes contrasting sharply with the forests and rugged peaks of the surrounding ranges, many parts of which are so precipitous as to be almost inaccessible. With the exception of a sheep station and one or two small farms along Bindi Creek, the district is uninhabited, the only part which has been surveyed by the Lands Department being the limestone area contained within the parish of Bindi.

## The Metamorphic Complex.

The basement complex of the Bindi area comprises rocks typical of the Metamorphic Complex of north-east Victoria. The eastern portion of the parish of Bindi is composed of regionally metamorphosed sillimanite-garnet-mica schists and gneisses, comparable with the rocks described by Howitt (1888) in the "Omeo Series," and later described as regionally metamorphosed Upper Ordovician sediments by Tattam (1929). In the western portion of the parish a gneissic granite is intrusive into acutely folded sandstones and shales, which show no trace of regional metamorphism. They are, however, lithologically identical with the series extending to the south of Bindi, which is mapped as Upper Ordovician by the Geological Survey The occurrence of such widely different metamorphic types within the parish of Bindi could be due either to extensive faulting or to a stratigraphical unconformity between the regionally metamorphosed series and the almost unaltered sandstones and shales. The sharp line of junction between the two formations seen at Junction Creek and

the absence of basal conglomerate in the sandstone-shale series suggests that faulting has been the more probable mechanism. In the regions to the south and south-west of Bindi, the Palaeozoic formations are similar in most respects to the rocks of the Junction Creek area, generally comprising indurated and silicified sandstones. The boundary line separating these types from the regionally metamorphosed Omeo series is defined by a system of faults, one of which strikes N.N.W. through the Bindi area. A similar abrupt junction to that at Junction Creek occurs at Tongio Gap, where Howitt (1888) describes a major fault striking N.W. and persisting for many miles.

*Schists and Gneisses of the Omeo Series.*

Howitt originally divided this series into two main groups of rock types:

(i) Schists and phyllites resulting from the alteration of a series of Upper Ordovician sediments.

(ii) Gneisses and schists produced by the effect of pressure metamorphism on the intruding granites, i.e., ortho-gneisses.

Both groups are present in the portion of the complex exposed on the western and northern slopes of Mount Bindi. Owing to the inaccessibility of the country, little is yet known regarding the relative positions of the bands of sillimanite schist and gneiss, graphitic schist, and biotite schist which make up this region. The various bands of schist and gneiss alternate rapidly, reflecting the original compositions of the sediments, which can be inferred to have comprised sandstones, aluminous shales, carbonaceous sandstones, and types intermediate between these. The general strike of the beds is slightly to the west of north, dips generally being erratic, but always at high angles. Lustrous, fine-grained, sillimanite schists are well developed along the southern bank of Junction Creek, immediately south of the limestone termination, and east of the extension of the line of faulting which determines the western boundary of the limestone. West of this line of faulting, the schists are absent, their place being taken by granite and indurated sandstone.

*Upper Ordovician.*

The ridges of indurated sandstone and shale occupying the south-west corner of the parish of Bindi represent the north-eastern boundary of the sandstones typical of the Swift's Creek district. In the lack of palaeontological evidence they are provisionally regarded as belonging to the lithologically similar Upper Ordovician formations of north-east Victoria. Although indurated and disrupted by a local granitic intrusion, they show no trace of the intense metamorphism which has affected the (?) Upper Ordovician rocks in the eastern portion of the parish. The

granite causing the contact metamorphism of the sediments is typical of the plutonic rocks of the metamorphic complex of north-east Victoria, showing petrographic similarity with both the gneissic granites of Omeo and the more normal granites of Ensay, to the south of Bindi. Movement along flow planes during the later stages of intrusion, coupled with the development of cataclastic structures by movement along shear planes subsequent to consolidation, has given the rock a foliated appearance, which is more strongly marked in the outcrops near Junction Creek, where the rock grades into an ortho-gneiss.

It is probable that a small area of sericite-chlorite schist on the northern slopes of Cairn Hill belongs here, since it shows little affinity to the rest of the Omeo schists. It probably represents a small roof pendant of Upper Ordovician, similar to those found to the west across the Tambo. Field relations at this point are rendered obscure by the presence of a number of massive quartz veins between the schist and the limestones. Mineralised fissures in the quartz contain chalcopyrite, azurite, and small amounts of gold and silver.

## Acid Extrusives.

Along their eastern boundary, the Bindi limestones rest partly on metamorphic rocks, and partly on an acid lava flow which occupies the north-eastern portion of the parish and the areas to the north, on the east side of Mount Tambo. This flow was included by Howitt (1876) in the extensive series of eruptives and pyro-clastics forming the "Snowy River Porphyries." Stirling, however, later (1886) described the flow at Bindi as distinct from the main mass of L. Devonian eruptives in eastern Victoria. The present work confirms Howitt's views, correlating the flow at Bindi with petrographically similar types at Mt. Cobberas, Wombargo, and Murrendel. Tuffaceous phases occurring at Bindi show the characteristic features of the fragmental rocks common in the "Snowy River Porphyry" complex. These tuffs are well exposed along the southern limits of the lava flow, comprising several varieties intermediate between massive red lavas and silicified white tuffs streaked and spotted with purple and red material. The similarity of this rock in the field to the conglomerates of Mount Tambo seems to have given rise to Stirling's misconception as to the "Lower" Devonian age of the latter series. The tuffaceous material definitely underlies the Middle Devonian, but, when sectioned, bears no resemblance to a true conglomerate.

A petrographic examination of the massive lava (see p. 23) shows that the rock is of the rhyo-dacite type, corresponding to dellenite as described by Brögger. The toscanites and quartz-latites approach the dellenites in composition, but are to be dis-

tinguished therefrom by slight differences in the composition of the plagioclase and the amount of quartz present, respectively. Considering the similarity between the flow at Bindi and other flows scattered throughout the Snowy River volcanic complex, it is expected that the bulk of the complex will eventually be shown to be composed of true "volcanic" rocks, so that the term "Snowy River Porphyries" should at present be replaced by the more noncommittal term "Snowy River Series." Such a series could be understood to include rhyo-dacites, pyroclastics and tuffaceous extrusives, as well as true hypabyssal porphyries and porphyrites, if the existence of such can be established. Skeats (1909) suggested that some of the more fluidal types should be termed rhyolites. Evidence is now pointing to the term "rhyo-dacite" as a useful general, though fairly exact, description of most of the rocks comprised in the "Snowy River Complex."

## Bindi Limestones.

NORMAL LIMESTONES.

The "Bindi limestones" consist of shallow-water marine limestones and calcareous shales, which have been shown on palaeontological grounds to be of Middle Devonian age. (Howitt, 1876; McCoy, 1877). The beds have been regarded as having originated under shallow water conditions in a small marine basin, isolated from the main sea in which the more extensive limestone deposits of the Buchan district were being formed. (Howitt, 1876; Whitelaw, 1898). However, the present boundaries of the limestones are not those defined by the limits of sedimentation in the original sea or estuary, but are largely fault boundaries. It is thus inferred that the Devonian limestones and conglomerates in this area once formed part of more extensive formations, the bulk of which has been removed by erosion. The existing remnants at Bindi have been preserved by down faulting. Howitt (1878) described similar extensive faults along the edges of the limestones at Buchan and Murrendel.

*Lithology*.—The limestones occupying the central areas of the tilted fault block have entirely escaped cataclastic disruption, whilst near the eastern edge of the fault block extreme deformation indicates the extent of the faulting. These latter features of deformation will be described below in the section on marmorised limestones. The normal limestone beds in the central areas show few signs of shattering or flexure, and preserve their original relations to one another. These beds comprise massive blue-grey limestones, with minor amounts of impure thin-bedded limestones. The thick massive limestones are rich in stromatoporoids and corrals, whilst the thin argillaceous beds are crowded with brachiopods. Along the north-eastern boundary a few outcrops of fine sandstone and shale are exposed.

Along Old Paddock Creek, black calcareous shales are interbedded with thin discontinuous bands of massive, sparsely fossiliferous, limestone. The alternation of shale and limestone is fairly regular, the distance between any two bands of limestone rarely exceeding 6 in. The conditions under which such a deposit could form would probably occur in a marine environment subject to a seasonal influx of water charged with fine silt. The presence of such argillaceous material in quantity would render impossible the growth of the fossils which usually characterize limestone deposits; thus it is found that the shale is completely unfossiliferous, whilst the recognizable forms in the limestone bands are both stunted and rare.

In general, the thick beds of "stromatoporoid" limestones are the purest in the area, and correspond closely with the normal Buchan limestones in lithology. Thinly laminated argillaceous limestones with innumerable brachiopods are widespread in the Bindi area, and are usually rich in both carbonaceous and sulphur-bearing impurities. The white chalky limestone mentioned by Whitelaw (1898) is a secondary deposit, similar in some respects to travertine. It is friable in texture, often with a "honey-comb" surface structure, and is most abundant on the dip slopes of the limestones.

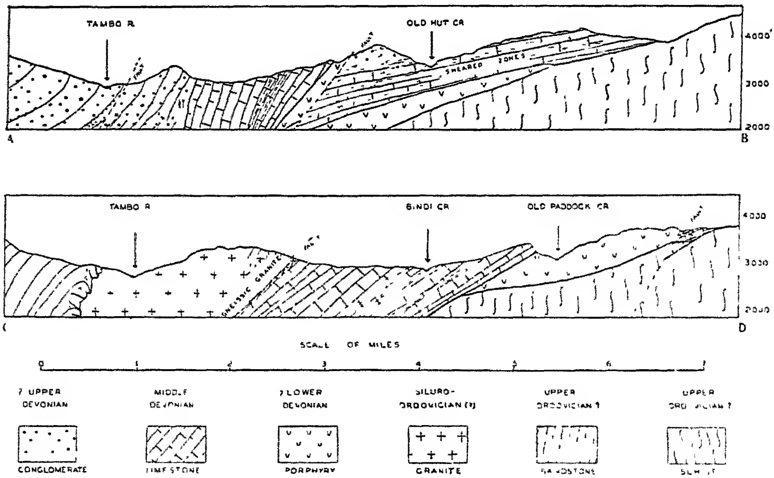


FIG 1.—Diagrammatic sections across the Bindi Limestones from A to B and from C to D on the geological sketch. Contours are approximate and vertical scale 1 inch = 4,000 feet.

*Field Relations.*—The whole of the unaltered limestones occupying the central area of the parish of Bindi appear to be contained in one single block, which has undergone tilting in a westerly direction combined with slight torsional flexing, giving gradually increasing dips as the northern boundaries are

approached. Dips in the southern portion of the area range from 15°W. to 30°W., whilst in the northern half of the area the range is from 50°W. to 80°W.

A continuous series of dips can be observed along Old Paddock Creek, where a traverse from west to east suggests that the major structure has originally been a broad, open, monoclinal fold of limestone, the western edge of which has been faulted into contact with the granite, whilst the eastern extension of the fold has been removed by erosion. The area of limestone further to the east seems to represent a down-faulted block which possibly formed the footwall of an extensive thrust fault, shearing along which has caused intensive distortion of the limestone and the Tambo conglomerates which here overlie them (see "Marmorised Phases"). Thus it is found that dips at the contact of the limestones with the granite are from 60°W. to 80°W., i.e., the beds dip into the granite at a high angle. Proceeding eastwards, the inclination of the beds gradually decreases, until on their eastern boundary they become horizontal, then, over a small area north of Old Hut Creek, they dip eastwards at about 30°. This is probably due to drag associated with the subsidence of the north-eastern block. The limestones cannot be traced any further eastward owing to the sudden appearance of sheared and distorted purple conglomerates belonging to the Mount Tambo series

An alternative view could be advanced regarding the structure of the limestones, whereby the beds are overfolded along a north-south axis, to form an acute asymmetric syncline with its axial line crossing Old Paddock Creek at a point about 600 yards east of the limestone-granite contact. The fact that no such axis could be detected in the beds along Old Paddock Creek discredits this synclinal hypothesis. Since the whole of the limestone outcrops across the area appear to represent beds conformable to one another, the total thickness of limestone and calcareous shale in the series is of the order of 3,000 ft.

The eastern boundary of the limestones is an erosion escarpment up to 200 ft. in height, which forms cliffs along the upper portions of Old Paddock Creek and Bindi Creek. Definite evidence that the beds were originally continued on towards the east, over the rhyo-dacite core of the fold, is provided by the occurrence of sheared and "stretched" marmorised limestones for some miles beyond the eastern boundary of the normal limestones. The significance of this occurrence has been apparently overlooked by Howitt and Whitelaw. Although Stirling (1884) recognized the northern limit of the zone, he did not attempt to explain the intensely sheared rock types.

Although earlier reports of Stirling and Howitt mention basal conglomerates in the Bindi limestones, which they emphasized as confirming the basin-deposition theory, no such basal conglomerates could be found along either the eastern or western

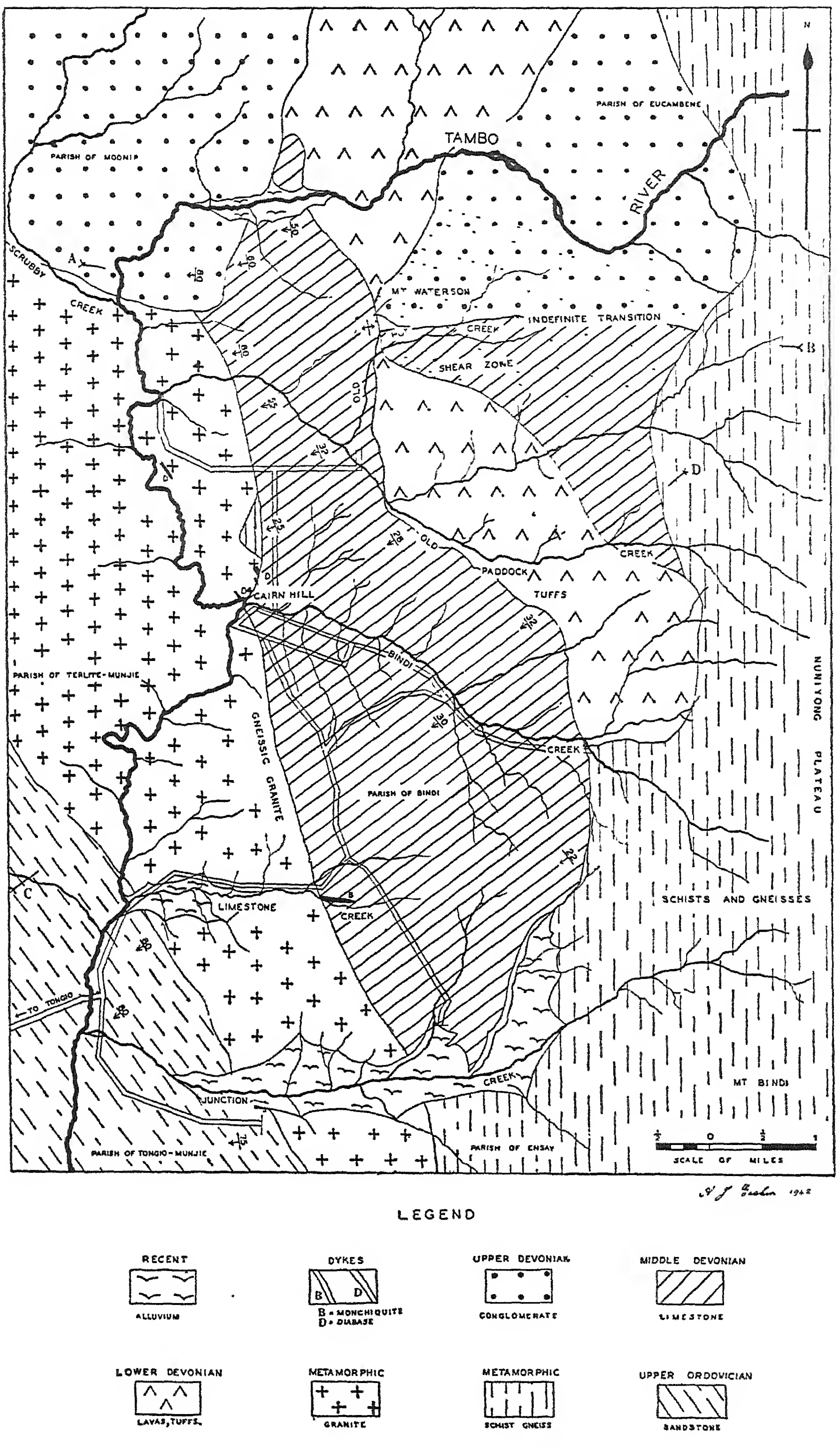


FIG. 2.—Geological Sketch Map of the Bindi Area

boundaries of the limestones. The basal beds of the limestone series are well exposed in the cliffs of the erosion escarpment, and everywhere it was noted that the basal beds were massive and shaly limestones exactly corresponding to the beds occurring higher up in the series. These calcareous beds rest directly on either the rhyo-dacite, its tuff phases (which strongly resemble conglomerates in the hand specimen), or the metamorphic rocks in the southern corner of the area. The supposed "basal conglomerates" may be identified with the uppermost "tuff" bands of the lavas.

In the extreme south of the parish, the limestones disappear at Junction Creek, without any apparent lithological or structural changes having taken place, and are replaced on the southern bank of the creek by precipitous cliffs of Upper Ordovician shales and sandstones to the west, and to east the metamorphic granite and schist of Mount Bindi.

To the north, the limestones pass under the conglomerates and sandstones of Mount Tambo. The two formations have strikingly similar attitudes, the extreme angular unconformity noted at Tabberabbera between Middle Devonian limestones and shales and Upper Devonian sandstones and conglomerates (Skeats, 1929) being absent. The southern extremity of the Mount Tambo beds overlaps the western boundary of the limestones to a slight extent, but in the field there is no indication of the mechanism by which this has been brought about. The limestones here dip at about 80°W., and, within a few yards, are abruptly replaced to the north by coarse felspathic sandstones and conglomerates of the Mount Tambo series in a massive sequence of beds striking parallel to the limestones and dipping like them at about 80°W. The north-eastern corner of the limestone area shows the beds dipping fairly steeply to the west, with a rugged erosion scarp where they have been removed from the crest of the fold, exposing once again the core of rhyo-dacite, which itself shows signs of broad folding and fracturing where it is exposed along the Tambo River.

The western boundary of the limestones is remarkable primarily for the straight-line junction between the sediments and the granitic rocks. In the field the line of junction can be traced for six miles over steep hills and down into valleys without any major deviations from a north-south line. This boundary cannot represent the boundary of a basin-like deposit, which should show an indented line of junction depending on the altitude of the surface outcrops. In addition, the limestone beds dip to the west throughout the area. A formation deposited in a marine basin, or subsequently converted into a structural basin by folding, would show beds dipping in opposite directions on either side of the area of outcrop, hence it must be assumed that the junction between the limestone and the granite at Bindi is the

result of faulting along a north-south line. Abundant evidence of cataclastic disruption can be found at the fault junction. Most of the disruption has apparently taken place in the border zone of the granite, which shows considerable shearing. Fault agglomerates and slickensided surfaces are developed to some extent on the hillsides north and south of Bindi Station, but elsewhere the rock in the crush zone is sheared and broken up into a characteristic mass of fine quartz particles interspersed with biotite, chlorite, and secondary calcite. The entire absence of any traces of thermal metamorphism in the limestones shows that the granite has not intruded these beds. Intensive search failed to reveal any evidence of recrystallization or even of induration in the limestones along their western boundary.

*Palaeontology.*—The fossils in the limestones, though abundant and often well-preserved, are limited throughout to a few characteristic generic and specific groups. A review of the literature has shown that the following forms from Bindi have been recorded.

STROMATOPOROIDEA.—*Stromatopora concentrica* Goldfuss, 1826.
*Syringopora speleana* Etheridge, Jr., 1902.

PORIFERA.—*Receptaculites australis* Salter, 1859.

ANTHOZOA.—*Favosites multitabulata* Etheridge, Jr., 1899.
(*F. gothlandica* of Stirling, 1886.)
*Campophyllum gregoryi Etheridge*, Jr., 1892.
*Cystiphyllum* (?) sp.

BRACHIOPODA.—*Atrypa aspera* Davidson, 1865.
*Atrypa reticularis* Linnaeus, 1767.
*Chonetes australis* McCoy, 1876.
*Spirifer yassensis* De Koninck, 1877.
(*S. laevicostata* of McCoy.)
*Spirifer howitti* Chapman, 1903.

PELECYPODA.—*Pterinaea* sp

CEPHALOPODA.—*Danaoceras* (?) *bindiense* Teichert 1939.
(*Phragmoceras subtrigonum* of McCoy.)
*Goniatites* sp. (?)

PISCES.—*Phlyctaenaspis* (?).
(*Asterolepis* of McCoy.)

Most of the forms previously recorded from Bindi were identified in the course of the present survey, although types such as the ganoid scales mentioned by Whitelaw (1898) and the Asterolepid recorded by McCoy (1877) were not observed. Fragmental forms occur which bear some resemblance to the *Phragmoceras subtrigonum* of McCoy, which has recently been re-described as a new form related to *Danaoceras* (Teichert, 1939). A thin, but well-defined band of blue limestone about 80 ft. up the cliff along the western bank of Old Paddock Creek is crowded with well-preserved casts of *Tentaculites,* closely comparable with *T. ornatus,* one or two specimens showing traces of striae between pairs of individual transverse ribs. *Leptaena* and *Orthis* are plentiful in the shaly limestones along Bindi Creek. A cast of a form strongly resembling *Cyclonema* was also found in the Bindi Creek beds. The massive limestones to the east of this locality yielded a large *Euomphalus,* and numerous sections of shells of the *Loxonema* type. Crinoid ossicles and long stems (up to 4 in.) are extremely abundant throughout the whole of the Bindi deposits, but no calices have been observed.

A comparison of the fauna with that of Buchan indicates general similarity, though the trilobites, gasteropods, and lamellibranchs found at Buchan are unknown or very rare at Bindi.

On the whole, the fossils are typically Devonian types, some such as *Spirifer yassensis* and *S. howitti* being characteristic of the Middle Devonian, whilst *Leptaena, Orthis, Chonetes* and others persist throughout both the Silurian and Devonian. An exact determination of the horizon of the deposit relative to the European series could probably be obtained by detailed examination of the Stromatoporoid or Coral faunas. Thus, if the previous identifications of *Stromatopora concentrica* are upheld, the possible age of the Bindi limestone series is restricted to the Givetian horizon of the Middle Devonian.

### Marmorised Limestones.

Rocks of both the Middle Devonian limestone series and the Mount Tambo conglomerate series are exposed over an area of about 5 square miles surrounding the upper reaches of Old Hut Creek. The appearance of these rocks in the hand specimen and under the microscope indicates that they have undergone intense shearing, with consequent elongation of the various sedimentary components along the shearing planes. The dominant mechanism of elongation could have been either " stretching " of the material in the direction of movement of the sheared layers (elongation along the " A " axis of the tectonite) or elongation due to " rolling " of the material between shear surfaces with consequent extension of the grains and pebbles in a direction parallel to the intersection of complementary shear planes, but at right angles to the direction of movement (i.e., elongation by rotation about the " B " axis of the tectonite).

The first process would require extensive intergranular movement along shear planes at a low angle to the horizontal (about 25° as shown by the dip of the elongated fragments). Such movement could only have been produced by thrust faulting. In the field, the direction of slip along such a fault, as deduced from the direction of elongation of the sedimentary components, is in approximate agreement with the direction from which the compressive forces producing the granite-limestone thrust fault in the west must have acted. There is thus some reason to attribute the distortion and marmorisation of these rocks to the action of a second thrust plane extending underneath the eastern boundary of the normal limestones.

Elongation by rotation about a "B" axis would correspond in the field to the action of normal block-faulting. The shear zone in such a case would be a downthrown block, defined by a north-south fault along its western edge. It seems very improbable that block faulting could result in a shear zone of such lateral extent as that exposed in this part of the Bindi area.

*Lithological Characteristics and Field Relations.*—The Middle Devonian beds in the shear zone comprise massive blue limestones grading into calcareous conglomerates, the latter being in turn replaced by the siliceous conglomerates of the Mount Tambo series. This apparent gradation suggests that the time interval between the deposition of these formations was not as great as their allocation to the "Upper" and "Middle" Devonian periods would suggest. It is possible, however, that intermixing of the two formations has occurred during faulting.

At the western boundary of the shear zone, the limestones are almost normal, with abundant recognizable fossils (Plate 1, fig. 5). Proceeding eastward, however, the shear planes become more pronounced until the rock grades into a fine-grained "marmorised" type, in which the bedding planes have been almost obliterated (Plate 1, fig. 6). As far as could be determined, the pinkish iron-stained seams which represent the original bedding strike approximately north-west, dipping at 50°–55° to the south-west.

The shear planes, along which the rock cleaves readily, strike at 68°–70° west of north, dipping in a southerly direction Towards the north, the limestones are gradually replaced by calcareous conglomerates, in which the pebbles are considerably elongated in the direction of the shear planes. The dip of the "stretched" pebbles along the direction of elongation is at a low angle to the west.

Further to the north in the shear zone, the calcareous conglomerates are themselves replaced by siliceous conglomerates, at first yellow to brown in colour, but ultimately showing the reddish-purple tints characteristic of the Mount Tambo beds.

The northern portion of the sheared area is composed entirely of these purple conglomerates, which are obviously the sheared representatives of the normal purple conglomerates exposed on the slopes further north at Mount Tambo. The strike of the shear planes in these latter conglomerates is rather different from that in the marmorised limestones, being 25 degrees west of north, whilst the dip is indeterminate owing to the massive nature of the bedding. Tension gashes are strongly developed at right-angles to the elongation of the pebbles.

Considering the extent and unusual lithological features of the sheared formations, it is surprising that so little mention of their occurrence has been made. Stirling (1884) in a note on the deposit suggested that the marmorisation was due to the quartz porphyry (rhyo-dacite) which he regarded as intrusive into the limestones. Howitt later discredited this view, and suggested that the changes in the limestones were due to the hydrostatic pressure exerted by an enormous thickness of overlying rocks. It is now apparent that a sufficient mass of rock could not overlie the limestones so as to marmorise one portion and yet leave the beds one hundred yards away almost unaffected. Whitelaw (1898) does not seem to have recognized the sheared easterly extension of the limestones, as his map shows the whole of this particular area as Upper Devonian conglomerate. The significance of a shear zone of such dimensions lies in the fact that its existence confirms, to some extent, the importance of faulting in the structural control of this particular portion of the Dividing Ranges.

## Mt. Tambo Series.

The course of the investigation into the relations of the Bindi limestones provided some opportunities of examining the formation which constitutes Mount Tambo and the surrounding rugged country extending southward to Mount Waterson in the parish of Bindi. Two significant facts were specially noted in regard to the age of the Mount Tambo beds:

(1) In every case where the normal contact relationships between the Mount Tambo beds and the Middle Devonian limestones can be observed, it is found that the limestones are inclined in the same direction and to much the same extent as the Mount Tambo beds, and underlie the latter.

(2) Although the relationships in the north-east of the area are complicated by a shear zone due to faulting, the Middle Devonian limestones are separated from the typical Mount Tambo conglomerates by a zone of calcareous and siliceous conglomerates which may represent transitional deposits connecting the two formations.

A rather obscure exposure on the limestone-granite junction about $1\frac{1}{4}$ miles south of Bindi Creek shows coarse conglomerates between the two formations, dipping at a slightly higher angle than the limestones, but in the same direction. The rock is identical with the basal bed of the Mount Tambo series as described by Howitt (1876) and contains fragments of quartzite, quartz, and indurated slate.

The inference to be drawn from these statements is that, although the Mount Tambo series is on a higher horizon than the Middle Devonian limestones, the relationship between these two formations is in the nature of a disconformity, in contrast to the well-marked angular unconformity between the Middle Devonian Tabberabbera shales and the Upper Devonian Iguana Creek beds. Hence, assuming that the Middle Devonian beds of Bindi and Tabberabbera are contemporaneous, it seems that the Mount Tambo beds should be placed on a considerably lower horizon than the Iguana Creek beds. The matter cannot be decided on palaeontological grounds, since, although the Upper Devonian age of the Iguana Creek beds is suggested by the presence in them of the Cordaites-Archeopteris flora, no authenticated fossils have ever been recorded from the Mount Tambo beds. A single fish plate has been found on the top of Mount Tambo, but its affinities are not restricted to the Upper Devonian. Selwyn (1866) reported "plant-beds" at Mount Tambo, but no traces of any such have ever been subsequently found.

Much of the lithology of the Mount Tambo beds has been described by Howitt (1876) and Whitelaw (1898) However, an examination of the beds of this series exposed in the parish of Bindi showed two types not previously recorded: (1) sheared conglomerates; (2) arkoses. The rocks of the former group have already been noted as the Upper Devonian equivalents of the sheared limestones. Notwithstanding their hard and brittle nature, the quartz pebbles and grains of the Tambo beds have been distorted by the faulting into long needle-like splinters. The formation covers an area of a few square miles in the north-east of the parish, the resistant character of the rock giving rise to the precipitous heights of Mount Waterson. The arkoses form the massive sequence north-west of the Bindi limestones. The formation is remarkably uniform throughout the first 200 feet from the limestone contact, the general appearance being that of a yellowish grit, containing rare rounded quartz pebbles. The extent of this arkose has not been determined in the field.

Section No. 6012 shows the arkose to consist of rounded quartz grains set, with numerous felspar fragments, in a fine-grained siliceous ground-mass.

The edges of many of the quartz grains are not smooth, however, but show angular projections and embayments, suggesting that little transportation preceded sedimentation. The large

angular fragments of felspar crystals also suggest rapid sedimentation at no great distance from the parent granite. The granitic rocks to the south of the outcrop are a possible source of the arkose components. However, the biotite, chlorite, and muscovite of the granitic rocks have not been found in the arkose. The quartz grains in the latter show intense internal strain effects, undulose and "shatter" extinction being much more prominent in these grains than in the quartz crystals of the granite (Plate I, fig. 4).

## Hypabyssal Intrusions.

*Pegmatite.*—Coarse tourmaline-bearing pegmatites, aplites and masses of graphic granite are common in the metamorphic "Omeo Schist" series in the south-east of the area. The dykes are similar in all respects to those commonly found throughout the whole of the north-eastern "Metamorphic Complex." One pegmatite vein occurs in the granitic rock in the south-west of the area.

*Diabase.*—A suite of decomposed basic dykes strikes north-west through the granite slightly to the north of Bindi Creek. The disturbed nature of the rocks in this region makes it impossible to trace the individual dykes for any appreciable distance, but all were found to end at the limestone contact. A well-exposed dyke in the bed of the Tambo River could be traced for 20 feet, but was then found to be cut off, presumably by faults. The dyke represents a fragment torn from a longer dyke by the faulting in the granite, there being many small fragments of similar dykes in the surrounding granite. These dyke fragments are almost indistinguishable from massive limestone in hand specimens. The dykes themselves are rarely more than 2 feet in thickness.

*Monchiquite.*—A peculiar type of basic dyke or dykes outcrops in the south-west portion of the limestones, immediately north of Limestone Creek. The accumulated thick soil on the hillside at this point obscures the shape of the outcrop as a whole, but fragments of the rock are exposed over an oval area of greatest length about 300 yards, suggesting a plug-like intrusion rather than a dyke. The surrounding rock is massive limestone, and fragments of it may be seen to be included in the basic dyke near the contact of the two rocks. The heat of the intrusion has only been sufficient to drive off the $CO_2$ of the limestone, leaving an impure yellow lime.

## Petrographic Descriptions.

[Numbers in brackets refer to slides in the collection at the Department of Geology, Melbourne University.]

SILLIMANITE SCHIST.

The hand specimen is a greenish-brown fine-grained lustrous schist. It outcrops along Junction Creek to the east of the indurated Upper Ordovician-granite series. A large part of the

section (No. 5991) is composed of sillimanite (fibrolite) in extremely fine felted fibres. A few shreds of reddish-brown biotite grade out into masses of fibrolite.

The large amount of sillimanite present—about 50 per cent. of the rock—in the complete absence of cordierite, pinite or andalusite, can conveniently be accounted for by assuming the metamorphic process to have been of a fairly intense thermal type, combined with a certain amount of orogenic pressure. The oriented structure of the schist, parallel layers of sillimanite alternating with chlorite-quartz layers, shows that stress conditions have been of importance during its formation.

All biotite has subsequently been chloritized, with the exception of isolated, red-brown shreds, occupying the centres of thick masses of fibrolite (Plate 1, fig. 3). Pleochroic haloes are frequent in the biotite and are represented in the chlorite by dark non-pleochroic stains. The haloes often surround recognizable zircons, which are plentiful in both schist and gneissic granite. Much of the fibrolite is intergrown with quartz, the needles of the former penetrating the edges of the quarz grains and giving them their serrated boundaries. Usually the central areas of the quartz grains are fairly free of included needles, but smaller grains are often split up into shred-like laminae, by bands of fibrous sillimanite. The simultaneous extinction of a number of these minute laminae over certain areas indicates the boundaries of the original grain. These grains are thus similar to the quartz sillimanitisé, as described by Barrow (1893), in which, however, sillimanite needles occupy the central portions of the quartz grains, leaving the edges of the latter relatively clear. A few crystals of orthoclase and oligoclase are scattered throughout the section. The similarity between the composition of the latter ($Ab_{72}An_{28}$) and that recorded by Tattam from many of the granitic and metamorphic rocks of the complex suggests that this felspar is magmatic in origin.

### Gneissic Granite.

Section No. 5996 represents the outcrops to the west of the schist-granite contact on Junction Creek. Megascopically, the rock appears to be a moderately coarse-grained granite, showing fairly strong foliation, with parallel orientation of large elongated felspars. In thin section, however, the foliation is not so apparent. Large anhedral grains of normal granitic minerals—quartz, felspar, and biotite—are cemented together by a fine-grained matrix of quartz and sericite. The fine-grained quartz is obviously of metamorphic origin, having been deposited from solutions produced by local breakdown under pressure of the large primary quartz grains, resulting in the typically crenulate outlines shown by the latter. The whole is an early phase of

true "mortar structure." Sericite, derived from the extensive decomposition of large areas of orthoclase and microcline-microperthite, is commonly intermingled with the siliceous matrix. A small amount of sericite is usually associated with crystals of oligoclase which are extensively fractured and kaolinized, with numerous embayments of clear secondary quartz, distinct from primary quartz, with its characteristic strings of minute inclusions.

Biotite is unaltered in the Junction Creek gneissic granite, but has been completely chloritized in the granitic rocks further to the north along the Tambo River. Well-defined rectangular patches of reddish biotite in minute flakes occur in Section 5996, and resemble the "knots" in schists described by Tattam (1929). Muscovite is ubiquitous throughout the gneissic rocks in the area. Small grains of zircon are common, and in Section 6001 large grains of apatite are gathered together with interstitial quartz, in a small segregation suggesting local concentration of mineralizers.

RHYODACITE.

A section (No. 5980) of the massive porphyritic rock forming the eastern bank of Old Paddock Creek contains phenocrysts of quartz, felspar, and altered ferromagnesian minerals, set in a fine-grained siliceous ground-mass containing much finely disseminated hematite. The quartz phenocrysts are embayed and devoid of inclusions. The felspar phenocrysts, approximately equal in number to the quartz, comprise plagioclase (sodic andesine $Ab_{35}An_{65}$) and orthoclase, and are extensively kaolinized. The plagioclase is approximately equal in amount to orthoclase. Phenocrysts of ferromagnesian minerals have been replaced by magnetite (now extensively oxidized to hematite), which frequently preserves forms characteristic of crystals of biotite, or, more rarely, pyroxene. Many of the magnetite clots have been drawn out along flow lines, resulting in the high concentration of hematite dispersed throughout the ground-mass, the hypocrystalline texture of which suggests devitrified glass.

An unusual feature is the association of minute crystals of hypersthene with a particularly large area of hematite. The intensity of the pleochroism and the low optic angle (about 30°–40°) indicate a variety rich in iron. The concentration of the hypersthene crystals along the margins of the hematite clot suggests that they have originated by reaction of the siliceous ground-mass with the magnetite. The sequence of reactions during the formation of the rock would thus include recrystallization of biotite prior to extrusion, then, on extrusion, break-down of the biotite to magnetite, and, finally, reaction of the magnetite with the remaining liquid to give small quantities of hypersthene.

TUFFACEOUS RHYODACITE.

Section No. 5997 represents the rock from the south-western limit of the lava flows. It is similar to the massive lava, but contains in addition numerous embayed fragments of quartz surrounded by thick mantles of minute, interlocking, quartz crystals.

DYKES.

(*a*) *Diabase.*—Section (5979) is taken from the dyke (D.4) exposed in the bed of the Tambo River. The rock is fine-grained, of trachytic texture, composed of laths of felspar and a ferro-magnesian mineral now so decomposed as to be indeterminate. The only other recognizable minerals are secondary calcite and sericite. The rock is conveniently described as " diabase " because of its appearance in the hand specimen and advanced alteration.

(*b*) *Diabase: (Chilled Margin).*—Section (5981) shows the contact of one of the diabases exposed on Cairn Hill, with the surrounding granite. A distinct border phase about 5 mm. in width extends in from the contact, which is sharply defined. Large crystals of augite, now extensively altered to serpentine, are set in a dark, fine-grained ground-mass, just inside the contact. These phenocrysts do not occur in the portions of the dyke away from the contact.

(*c*) *Monchiquite.*—This rock, which forms the basic plug near Limestone Creek, varies in appearance from a dense, black, glassy material, to a red-brown mass set with numerous black phenocrysts of hornblende, ranging up to an inch in length. Sections (Nos. 5983–5989) show that the texture varies from basaltic, with numerous small phenocrysts, to porphyritic, with a hypocrystalline ground-mass. The porphyritic variety appears to represent a chilled border phase, and often contains fragments of indurated limestone.

The sections show a variety of stages of resorption of hornblende, which is of the oxy-hornblende type, pleochroic from yellow to dark red-brown. During resorption, magnetite dust and pyroxene (titanaugite) are formed, the magnetite gradually extending throughout the body of the phenocrysts (Plate 1, fig. 2). Depending on the relative movement between the phenocryst and ground-mass, the pyroxene is either swept away as it produced or deposited as a shell around the parent hornblende. A striking instance of this latter formation is shown in Section 5985 (Plate 1, fig. 1), where the parent hornblende has formed an optically continuous shell of pyroxene and magnetite around itself, thus shielding the inner hornblende from contact with the ground-mass. At a later stage, this shell has been breached, allowing the ground-mass to pour in. In all instances where

pyroxene has crystallized round hornblende, the "C" axes of the pyroxene shell, and the inner hornblende fragments, coincide. The extinction positions of the shell and core are thus separated by an angle of about 30°–40°. A similar series of resorption stages is described by Larsen (1937) in the hornblendes of the Colorado andesites. The evidence in these lavas suggested that concentration of mineralizers rather than pressure conditions is the determining factor in the amphibole-pyroxene equilibrium. Thus as the mineralizing vapours escape on extrusion, the hornblende becomes unstable and breaks down to pyroxene. In the case of the small hypabyssal intrusion at Bindi, most of the resorption must have occurred before final intrusion as a dyke or plug, i.e., loss of mineralizers must have occurred while the magma was contained in a subterranean chamber large enough to maintain a high temperature for a period of time sufficient for most of the resorption to take place. Numerous small olivines are present in all sections, rarely attaining large dimensions, and usually much altered to serpentine. The ground-mass is composed of small laths of oxy-hornblende and titanaugite set in a glassy base containing rare minute felspars. A few of the larger pyroxene laths have a green central zone, which may be soda-augite.

MARMORIZED LIMESTONE.

Section No. 6011 represents the fine-grained pinkish "marble" outcropping in the centre of the shear zone near the locality commonly known as "Marble Gully." The rock here represents a fossiliferous limestone which has been subjected to intense shear, so that most of the original structure has been obliterated.

Microscopically, the rock is composed of minute grains of calcite, interlaminated with carbonaceous material and hematite. The minute size of the individual calcite grains renders their examination difficult, but their appearance in elongated masses, which "tail off" into the surrounding matrix, suggests considerable intergranular movement under conditions of shearing stress, rather than recrystallization under pressure.

Section No. 5982 is taken from a calcareous conglomerate outcropping a short distance north-west of the locality of Section 6011. The slide contains a pebble of massive blue limestone about 1 inch in length, which shows a moderate amount of recrystallization, and considerable elongation with development of tension gashes and slip planes. Two distinct groups of shear surfaces can be observed.

(1) The trace of the (ab) plane of the tectonite is not well defined in this particular section, but, as far as can be determined, it makes a slight angle with the axis of elongation of the pebble as a whole. The

actual elongation of the pebble has thus been produced by a mechanism distinct from that of direct rupture, which, although it is responsible for the S surfaces of Group (1), has produced only a subsidiary distortion of the pebble.

(2) The main process which has caused the elongation of this particular pebble has been gliding along the slip planes of the individual calcite crystals. The minutely displaced lamellae are everywhere well defined, and show a decided statistical preference for one particular plane in the fabric. Sander (1930) has shown that all such lamellae boundaries in deformed calcite grains are crystallographic "e" planes (0112). Although it can be stated that the rock is a tectonite which shows little mimetic recrystallization, the evidence for translation along the single slip-plane mentioned above is not reliable enough, when taken from a section on an ordinary microscope, to show that the fabric has not been produced by B-rotation. Thus, it is still possible that a universal stage determination would show a series of intersecting slip planes all parallel to a well-defined "B" axis.

Tension gashes, although normal to the axis of elongation, have been filled with crystals of secondary quartz which show parallel alignment along a direction which makes an angle of 20°–30° with the axis of elongation, i.e., the crystals are arranged "en echelon" in each tension gash. It seems necessary, therefore, to recognize two distinct phases of tectonic activity, the first of which produced the tension gashes during elongation of the pebble, whilst the second gave rise to the orientation of the quartz crystals. The undulose, sub-parallel extinction of the quartz suggests that pressure operated after, as well as during, the growth of the crystals.

## Age Relations and Tectonics.

*Upper Ordovician.*—At Bindi, rocks of this age comprise both contact and regionally metamorphosed types. Both types are, as far as is known, contemporaneous, and are distinguished by the degree of alteration. The fact that both are represented in the limited area of the parish of Bindi is probably due to extensive faulting along a line striking N.N.W. through this area.

(?) *Siluro-Ordovician.*—The granites which have intruded and altered the Upper Ordovician sediments are provisionally classed here. They have been tentatively classed as Lower Devonian by previous workers (Skeats, 1931). However, their relations with

the overlying Middle Devonian rocks at Bindi show that the contact is in the nature of an enormous unconformity, the extent of which can be assessed from the following evidence:—

(1) The metamorphic basement complex comprises intensely folded schists and gneisses, whilst the overlying formations are relatively flat-lying lavas and Middle Devonian limestones.

(2) The mineral content of the sillimanite-garnet schists and gneisses indicates that they were formed under conditions of temperature and pressure such as would exist near the intruding granites, in a geosyncline during orogenesis. A considerable period of time would be required for the removal of the upper levels of the folded geosyncline before the flat-lying limestones could be deposited. The interval between Lower and Middle Devonian seems inadequate.

*Lower Devonian.*—Lavas and tuffaceous extrusives underlying the Middle Devonian limestones in the north-eastern districts of Bindi are provisionally grouped as Lower Devonian. They are identical with the massive varieties among the Snowy River "porphyrites" underlying the Buchan limestones. Howitt (1878) has shown that these latter flows are conformable to the Middle Devonian, grading upwards through calcareous breccias and tuffs into normal limestones, so that their age may possibly be early Middle Devonian. Evidence relating to this point has been collected and correlated by Professor E. W. Skeats (1909, p. 182).

*Middle Devonian.*—The Bindi limestones are placed here on palaeontological evidence. They show some faunal differences from the Lower Devonian (?) Lilydale limestones, but show similarities with the Buchan and Tabberabbera beds. The Mount Tambo beds may belong here, as no marked unconformity is apparent between their basal members and the top of the limestone series.

*Upper Devonian.*—The Mount Tambo series is provisionally allotted to an early Upper Devonian age. The fact that this series has been involved with the Middle Devonian in an orogeny which is possibly connected with orogenic activity in Central Victoria towards the close of the Devonian, suggests that the Tambo beds are older, and the Iguana Creek beds are younger, than this orogenic period. This assumes that the diastrophism affecting the Tambo beds was not of local character.

*Post-Upper Devonian.*—The monchiquite penetrating the limestones is placed here. The rock resembles the Tertiary dykes in other parts of the State. Rock sections in the Howitt collection

show that an exactly similar type occurs at Back Creek, Buchan, though its stratigraphical relations have not been observed by the author.

The evidence to be found at Bindi is not complete enough in itself to allow a definite decision to be made regarding the course of events in the tectonic history of the area. A detailed survey of the districts to the south and north-west would have to be made before any suggested sequence of events could be regardeed as proved However, the following observations have suggested the sequence that will be given below:—

(1) There is a considerable difference in constitution between the rocks forming the western side of the igneous-metamorphic basement and those forming the eastern side of the area. No transition phases could be found on an east-west traverse along Junction Creek. By analogy with the similar petrographic break which occurs along the Tongio Gap fault (about 10 miles west of Bindi), it is suggested that the abrupt junction in the basement complex has been brought about by extensive movement along a pre-Middle Devonian fault.

(2) The limestones dip west at an average angle of 30 degrees, as far as the granite boundary. Since the contact here is not intrusive, and the dips at the contact increase to 60°–70°, the only possible explanation is that of a fault junction. This contact can be observed in a cliff section in the Tambo valley, and suggests that the granitic rocks have been thrust over the limestones. Mineralized quartz veins are prominent along this fault junction and slickensided surfaces are common in the nearby granite.

(3) In the marmorized zone in the north-east of the parish of Bindi, the extent and intensity of the deformation provide confirmatory evidence of the importance of fault action in the tectonic history of the area. The faults in this zone are not sharply defined, but are probably of the same nature as the thrust fault in the west of the parish.

From the above points, the following sequence is suggested:

(i) Pre-Devonian faulting, which is required to bring the highly metamorphosed Omeo series into contact with little altered sediments which are, as far as is known, contemporaneous. Subsequent deposition of the Devonian limestones and conglomerates, coupled with

later thrust faulting along the line of the pre-Devonian fault, has obscured the actual position of the latter.

(ii) The extrusion of the acid lavas and the deposition of the limestones and conglomerates was followed (probably at the close of the Devonian) by an era of strong compressive forces directed along an east-west line. The granitic rocks in the basement complex of eastern Victoria yielded to this compression by breaking up along thrust planes into crystalline wedges. The overlying Devonian sediments were folded to an extent depending on their distance from the orogenic regions of Central Victoria. Thus, at Tabberabbera, the folding of the Middle Devonian rocks is acute, whilst at Buchan, further east, it is much less intense. At Bindi, only a thin lava flow separates the Middle Devonian limestones from the crystalline basement. Thus, movement along thrust faults in the basement rocks has brought portion of the basement complex above the level of the limestones. The western extension of the limestones has been sharply cut off, whilst their eastern extension has been drawn out in a shear zone some three miles in width. Conglomerates of the Mt. Tambo series have also been involved in this shear zone, whilst some of the western members of the series have been forced upwards by the granitic wedge, great masses of quartzites and contorted phyllites being developed along the contact of the wedge with the overlying conglomerates.

## Summary.

The basement rocks at Bindi comprise types characteristic of the metamorphic complex of north-east Victoria. They are unconformably overlain by acid lavas which form part of the Snowy River Volcanic Series. The extreme nature of the unconformity suggests that the Lower Devonian age previously given for the granites of the metamorphic complex should be reconsidered. Middle Devonian limestones conformably overlie the acid lavas and tuffs. Their lithological, palaeontological, and structural characteristics are described. The Mount Tambo series, comprising conglomerates, sandstones and arkoses, overlies the Middle Devonian limestones, with little or no angular unconformity. Both the Mount Tambo series and the Bindi limestones have been involved in a series of thrust faults, developed in the underlying crystalline rocks. The sedimentary series owe their

preservation and present attitudes to this thrust faulting. An extensive zone of intense rock deformation occurs in the east of the area, and is shown to be due to fault movement.

In conclusion, I would like to acknowledge my indebtedness to Professor H. S. Summers and the staff of the Geology School for their ready advice and assistance during the progress of this investigation; to the various students of geology, whose companionship made field investigations in little-known and rather inhospitable country not only possible but enjoyable; and to Associate-Professor E. S. Hills especially, for his invaluable discussion and criticism of the ideas expressed in this paper.

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## Description of Plate.

Fig 1.—Monchiquite. Bindi. Basal section of augite-magnetite shell during resorption of oxy hornblende phenocryst.

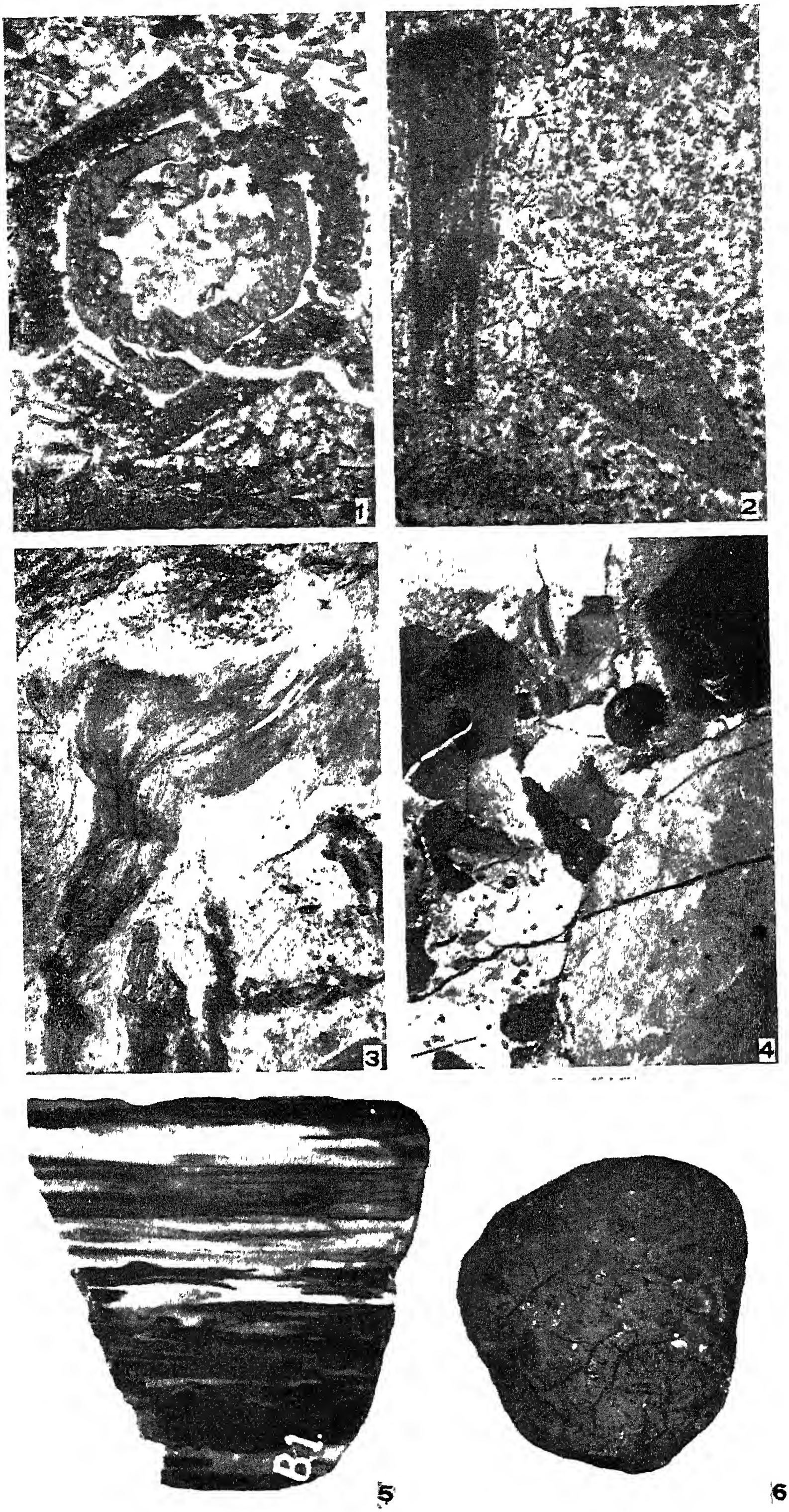
Fig 2.—Monchiquite. Bindi. Early and late stages in the resorption of oxyhornblende phenocrysts. The left-hand phenocryst has been almost completely replaced by magnetite and augite.

Fig 3.—Sillimanite Schist. Junction Creek, Bindi. Contorted mass of fibrolite needles, surrounding shreds of a mineral resembling biotite.

Fig 4.—Arkose. Bindi. A rounded quartz grain appears in the lower right-hand corner. The matrix is composed of fragmentary quartz, plagioclase and orthoclase.

Fig 5.—Marmorized limestone from shear zone. Bindi. The black streaks represent traces of shear planes.

Fig. 6.—Normal limestone. Bindi.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# Art. V.—*Mechanism of Abnormal and Pathological Growth: A Review.*

By B. J. GRIEVE.

Botany School, University of Melbourne.

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## Abstract.

Recent work is reviewed on the mechanism of abnormal and pathological growth in plants with special reference to those effects induced by *Bacterium tumefaciens*, *Bacterium solanacearum* and *Rhizobium* spp. The hypothesis that indole-3-acetic acid, produced by the organism in the plant, induces the cell proliferation or other stimulation effect is regarded as unlikely.

While the phenomena still strongly suggest the working of a growth-substance mechanism, researches so far have not substantiated the alternative hypothesis that the physical presence of the bacteria stimulate the plant to increased production of growth-substance leading to cell proliferation.

Other trends in recent research on this problem are indicated.

In a number of plant infections, growth correlations are disturbed, such disturbance being reflected by overgrowth, inhibition of growth, development of new organs or growth movements. For many years these conditions have been used in symptomatology without more than a passing suggestion as to how they were brought about. With the discovery of the auxins and other synthetic growth-substances and the recognition of the similar effects they are able to produce in healthy plants, attention has been increasingly directed toward the elucidation of the mechanism of abnormal and pathological growths.

The original viewpoint was, that since growth-substances were so important in the normal development of plant tissues, the finding of their presence in unusual amounts in certain abnormal tissues would indicate that they were responsible for these conditions. With increasing research in this field this viewpoint has undergone some modification. The present review represents a summary of progress made and of present trends.

### Types of Abnormal and Pathological Growth.

The literature in plant pathology contains numerous references to abnormal conditions induced in plants as a result of fungal, bacterial and virus infection. These conditions may arise from

successful parasitism or from controlled parasitism and may be delimited as follows:—

*Overgrowth.*

(*a*) Galls, tubercles or callus formation due to rapid multiplication of cells (hyperplasia) and increase in cell size (hypertrophy), whereby a more or less irregular overgrowth appears on shoot or root. Examples include Crown Gall, Club Root, Maize Smut, Rust Galls, Fiji Disease of Sugar Cane, Root Tubercles of Leguminosae and Swollen Leaf Teeth of Ardisia.

(*b*) Stimulation of cambial and other meristematic centres leading to abnormalities in size and number of parts. Examples include Witches Brooms, Fasciation, Crown Gall, Hairy Root, Big Bud of Tomato, Virus enations.

*Adventitious Root Formation.*

Roots arising in unaccustomed places on the stems of intact plants. These occur in Bacterial Wilt of Solanaceae, Crown Gall, Fusarium Wilt of Tomato and Bacterial Canker of Tomato.

*Growth Movements.*

Nastic Responses. Change of position of a bilaterally symmetrical organ due to differential growth. Epinasty and hyponasty, expressing conditions where the upper or lower side respectively of a dorsi-ventral leaf grows faster than the other, leading to a downward or an upward bending of the leaf. Examples include Bacterial Wilt of Solanaceae, Crown Gall, Fusarium Wilt of Tomato and Rose Wilt Virus.

Many of the abnormal growth effects listed above may occur in the same plant as a disease runs its course.

The fundamental problem in all these cases is the explanation of the physiological cause of the atypical cell multiplication and organ formation and movement. This has been pointed out by Riker and Berge (1935), and Riker (1939) in their studies on Crown Gall. Investigation so far has been confined to analysis of relatively few of the atypical growth effects. For the better appreciation of the investigations to be described, it appears desirable to outline briefly the auxin theory of growth, salient features of the effects induced by certain synthetic growth substances and the essential techniques involved.

## Outline of the Auxin Theory of Growth and Effects on Plants of Certain Synthetic Growth-substances.

The idea that a hormone is concerned in growth and growth-movements goes back over a quarter of a century, but success in obtaining an active substance from the coleoptile tip of *Avena* was first obtained by Went (1928). His fundamental experiment was to extract growth-substance by cutting off the tips of

oat coleoptiles and placing them upon a small rectangular plate of moist agar. After one to two hours the tips were removed and the agar plate cut up into blocks of equal size and placed on one side of the stumps of decapitated coleoptiles. The result was a curvature away from the agar blocks (negative curvature), indicating that some chemical growth-promoting substance had diffused out of the tips into the agar and then out of this into the decapitated coleoptiles. The degree of curvature was proportional, within limits, to the concentration of the substance in the agar blocks and the method has been widely applied in the comparison of the amounts of growth-substance in different plant parts and the interpretation of tropic phenomena. There appears little doubt that cell elongation is promoted by the presence of the plant growth-substance. On the other hand the application of this same substance to roots retards their growth.

By another line of research Nielsen (1928, 1930), demonstrated that a fungus, *Rhizopus suinus*, excreted into its culture medium a substance which could be extracted with ether and which induced curvature in *Avena*. A similarly active substance was also obtained from bacteria by Boysen-Jensen (1931). This substance, which was also found in urine (Kogl, Haagen-Smit and Erxleben, 1934), was shown by Kogl and Kostermans (1934), and Thimann (1935) to be identical with indole-3-acetic acid. The name hetero-auxin was coined for it. Prior to the identification of hetero-auxin, Kogl and Haagen-Smit (1931), found human urine to be rich in an active substance, since isolated in crystalline form and named auxin. Later Kogl, Erxleben and Haagen-Smit (1934), discovered and isolated a second active substance (distinct also from hetero-auxin) in urine. The original auxin was then designated auxin "a" ($C_{18}H_{32}O_5$) and the new one auxin "b" ($C_{18}H_{30}O_4$). These with hetero-auxin ($C_{10}H_9O_2N$) comprise the auxin group. All three are active in the *Avena* test. Hetero-auxin can be readily synthesized, but so far the other two have not.

Subsequently a variety of growth-substances were synthesized of which we may name $\alpha$-naphthalene-acetic acid, $\beta$-3-indole propionic acid and $\gamma$-3-indolebutyric acid. The above named acids were also found to be active in the *Avena* test (Avery, Burkholder and Creighton, 1937).

Hitchcock (1935) opened up a new field of investigation which has a close bearing on abnormal growth, by his experiments on the effect of introducing hetero-auxin and other synthetic growth-substances in lanoline or in water solution into such plants as tomato and tobacco. He found that various growth phenomena including epinastic response, cambial stimulation and adventitious root formation followed such application. Some synthetic compounds while producing the above effects in tomato plants were not active in the *Avena* test.

Certain members of the vitamin complex are being investigated in relation to abnormal and pathological growth and may prove of some importance in the interpretation of these phenomena. Thiamin (Vitamin $B_1$) which is produced by the normal plant is recognized as a root growth factor (Bonner, 1938).

## Techniques.

In quantitative work on growth-substance in plants, certain specialized techniques are used which may also be briefly outlined here to clarify statements as to methods used in investigations on abnormal growths produced by infective agents.

1. *Diffusion Technique and* Avena *Test.*

A modification of Went's original hormone diffusion method is used. The cut surfaces of normal (control) and abnormal tissues are placed on separate agar plates and the growth-substance present allowed to diffuse into the agar over a two-hour period. Each agar plate is then cut into twelve small blocks which are applied unilaterally to sets of decapitated *Avena* coleoptiles. Bromide prints record the negative curvatures after a two-hour period and the relative amounts of growth-substance diffusing from the normal and abnormal tissues can be assessed. This method has, however, been found to be of limited value for comparative investigations when dealing with green plants such as tomato.

2. *Ether Extraction of Growth Substance.*

A valuable method involving ether extraction developed by van Overbeek (1938), has been modified to suit conditions for investigations on abnormal growth. In the author's modification, normal and abnormal plant parts taken from "paired" plants are allowed to extract overnight at 4°C. in specially purified ether. The ether is evaporated on an electric hot-plate at a temperature below 60°C., down to 2 cc. in each container, transferred by pipette to centrifuge tubes which are standing in boiling water, so that the remainder of the ether is rapidly boiled off. Then 1 cc. of 1·5 per cent. agar is added to the tubes and thoroughly mixed with the residues. After two to three hours the agar is remelted and poured into small brass moulds. The chlorophyll-containing layer is sliced off and plates of standard size (8 x 10·7 x 1·5 mm.) cut from the agar. These again are cut into twelve blocks of equal size and applied unilaterally to *Avena* coleoptiles. Emphasis has been placed by some workers on the necessity for complete removal of auxins from plant tissues by repeated extractions but there appears no reason why the amounts obtained in a single extraction should not represent the relative amounts of free auxin present in the normal and abnormal tissues.

3. *The Pea Test.*

Briefly this consists of measuring the inward curvature of split portions of etiolated pea stems, which curvature occurs in the presence of certain growth-substances including indole-3-acetic acid. The method was developed by Went (1934). Thimann and Schneider (1939) have devised a similar but much more delicate test, using split coleoptiles of *Avena.*

4. *Treatments with Indole-3-acetic acid (Hetero-auxin) and other Synthetic Growth-Substances.*

These substances are frequently mixed with lanoline (method of Laibach, 1935) before application to stems or petioles of test plants. Concentrations ranging from 0·01 per cent. to 3·0 per cent. have been used. They may also be effectively introduced into test plants from small glass tubes drawn out to a capillary. The tube is filled with a water solution of the growth-substance and the capillary end of it inserted into the stem so that the liquid can slowly drain into the tissues (method of Zimmerman and Wilcoxon, 1935). Hetero-auxin can also be introduced into the plant through intact roots, by watering the soil with a strong water solution (Hitchcock and Zimmerman, 1935).

5. Phycomyces *Assay for Vitamin $B_1$.*

The fungus *Phycomyces Blakesleeanus* requires an external supply of thiamin (vitamin $B_1$) for growth and from this fact Schopfer and Jung (1937) have developed a quantitative biological assay. The fungal spores are sown into a basic thiamin-free medium to which thiamin extracted from test plant material is added. Comparison may then be made of the relative thiamin contents of normal and abnormal tissue on the basis of dry weight of fungus formed in a standard time.

## Overgrowth.

### 1. Crown Gall.

Some overgrowth conditions are due to strong parasitism, while certain others again arise from controlled parasitism (under which heading we can include symbiosis). One of the best known of the former and one on which a considerable volume of information is available, is Crown Gall. These galls arise on plants through parasitism by *Bacterium tumefaciens* Sm. & T. and this disease has been the subject of a great many studies, not only on account of its intrinsic interest but also because of its suggested analogy with cancerous conditions in man. Following infection, proliferation of cells leads to callus and gall formation, the galls being either primary or secondary. Other growth phenomena also occur and may be mentioned here, although their

physiology will be discussed later. Adventitious roots were frequently observed to be pre-ent in the vicinity of the growing galls. Smith, Brown and Townsend (1911), recorded their presence originally but detailed observations were first made by Brown (1929). She showed that Paris Daisy and Balsam plants in particular, reacted to inoculation by strong adventitious root formation in addition to gall formation. Epinasty of leaves of infected plants does not appear to have been recorded before 1937, although as Locke, Riker and Duggar (1937, 1938) point out, this phenomenon doubtless had frequently been observed by those studying Crown Gall.

Smith (1922), and Riker (1923) showed that the cambium was stimulated to activity in the presence of *B. tumefaciens*. Riker (1923), recorded the course of the early cell divisions initiating gall formation following infection. The walls were laid down in the portion of the mother cell near the intercellular spaces containing the bacteria. Up to the time when they could still be clearly observed, such cell walls formed a more or less distinct sheath round the bacteria.

There appears to be general agreement that the hyperplastic and hypertrophic growth, which, in various manifestations, generally follow Crown Gall inoculations, is due to some influence exerted by the bacteria. Crown Gall appears ideal as a test case for evolving an explanation of the physiological cause of the atypical cell multiplication, and prior to the development of the growth-substance theory, a considerable body of literature had already grown up concerning the possible importance of a great variety of chemical substances. These have been critically reviewed by Riker and Berge (1935), and will not be considered here, this review being concerned with the approach to Crown Gall through studies on growth-substance.

The view that growth-substance is concerned in Crown Gall formation arises from the fact that a close analogy exists between the stimulation effects induced in plants by such substances and the symptoms of the disease. Brown and Gardner (1936), and Kraus, Brown and Hamner (1936), demonstrated that indole-3-acetic acid could stimulate the multiplication of cells in French Bean plants, leading to the formation of galls which were structurally closely similar to those arising after infection by *B. tumefaciens*. Other points of similarity were recorded by Locke, Riker and Duggar (1938). Responses which suggest an increase in the amount of growth-substance present in infected plants include (1) epinasty of leaf petioles, (2) increased initiation of adventitious roots, (3) stimulated cambial activity, (4) inhibited development of certain buds, and (5) delayed abscission of senescent leaves.

With these similarities in mind, research on the mechanism of cell proliferation in Crown Gall has led to the formulation of the following hypotheses:—

(1) The parasite produces a growth-substance in the course of its metabolism which incites the cells of infected plants to abnormal division.

(2) The host plant reacts to the presence of the parasite by an excessive formation of auxins which induce the hyperplasia.

(3) Growth-substances produced by the parasite and by the host are jointly responsible for gall formation.

A viewpoint recently suggested, which has arisen out of negative evidence in relation to the above hypotheses, may also be listed here It is to the effect that growth-substances of the auxin or hetero-auxin type are not important in relation to gall formation, but that other phyto-hormones, possibly of the vitamin complex, may be concerned.

It appears desirable to consider each of the above hypotheses in the light of the experimental evidence presented.

*Growth-substance Production by the Parasite.*

Nemec (1930) studied the effect of smearing some fresh culture of *B. tumefaciens* on the cut upper surface of chickory roots held under moist air conditions. He found that vigorous callus development was followed by adventitious root formation. Normally, buds developed from the cut upper surface but these were inhibited in the presence of the parasite. Nemec concluded that growth-substance from the bacteria was responsible for the effect. Brown and Gardner (1936) showed that it was possible to extract from the culture in which *B. tumefaciens* had grown, a growth-substance capable of inducing galls. These workers adopted the view that it was not the mere presence of the organism which leads to overgrowth, but rather the stimulus of certain products of its metabolism. In a later paper (Brown and Gardner, 1937), they suggested that secondary galls were also due to some stimulating substance which travelled through the stem, after being given off by the parasite at the site of the primary gall. Link, Wilcox and Link (1937) and Berthelot and Amoureux (1938) claimed that *B. tumefaciens* produced hetero-auxin in culture. The latter workers considered that this growth-substance played an important part in the genesis of Crown Galls. The former workers found that ether extracts of broth cultures of the parasite caused local killing in addition to stimulation effects, when applied to test plants. This indicated that some substances other than hetero-auxin were present in the crude ether extract. They concluded, however, that hetero-auxin was a chemical agent by means of which, possibly in conjunction with others, *B. tumefaciens* induced galls.

Gioelli (1940) tested the effect of filtered cultures of *B. tumefaciens* on plant tissue cultures of *Sterculia platanifolia*. He found that cambial stimulation occurred which was similar to that induced by hetero-auxin. This led him to conclude that the organism induced the proliferation by the action of hormones.

Locke, Riker and Duggar (1938, 1939*a*) first reported evidence which was in conflict with the hypothesis being considered. They demonstrated that both attenuated and virulent cultures of *B. tumefaciens* produced approximately the same amount of growth substance in media. There appeared to be no relation between the ability of the one and the inability of the other to form galls, and their ability to form growth-substance in culture. These workers concluded that it seemed better to reserve judgment regarding the importance of the role played by hetero-auxin in the development of Crown Gall. Other evidence adduced in support of their view was as follows:—(1) Indole-3-acetic acid was relatively ineffective in stimulating tissue inoculated with an attenuated strain of Crown Gall organism, whereas very small amounts of active substance diffusing from virulent gall inoculations were highly effective in this respect. (2) Responses of various plants, including bean and sunflower, to indole-3-acetic acid, did not parallel their response to Crown Gall bacteria. (3) The volume of culture which must be extracted and the number of bacteria present to give a small amount of growth-substance (optimum value 125 gammas per litre) is out of all proportion to the number of organisms present in a typical Crown Gall.

Grieve (1940) also reported that pathogenic and non-pathogenic cultures of *B. tumefaciens* produced approximately equal amounts of growth-substance. A similar result was obtained for *B. solanacearum, Aplanobacter michiganense and B. flaccumfaciens*. These results indicated that production of indole-3-acetic acid in media was not peculiar to bacteria which induced abnormal cell division, since *B. flaccumfaciens* did not produce any such effects in its host, the French bean. It is interesting that it is this plant which has proved so useful in demonstrating cell proliferation arising from infection by *B. tumefaciens*, by extracts of *B. tumefaciens* and by synthetic indole-3-acetic acid. The inference may be drawn from the above experiments that there is no necessary relation between growth-substance formation in media and in the host.

White (1942) claims that it is possible to produce a gall on a plant by implanting, at cambium level, a fragment of tissue derived from a bacteria-free tumour arising originally on a plant inoculated with *B. tumefaciens*. This would appear to provide further evidence that a product of bacterial metabolism is not causally involved in the atypical cell proliferation.

The writer is of the opinion that the balance of evidence indicates that it is unlikely that bacterially produced hetero-auxin plays any major role in atypical cell multiplication.

*Excessive Growth-Substance Production by the Host.*

Leonian (1937), in the course of a review of "Growth Hormones in Plants" (Boysen-Jensen), suggested in the case of Hairy root, tumours, galls and other pathological conditions, that such abnormal growths were the result of excessive production and concentration of auxins in an attempt to overcome the invader (sic), rather than to growth-substances furnished to the host plant by the pathogen. Link, Wilcox and Link (1937) also suggested that the parasite "probably not only furnishes a more or less continuous supply of hetero-auxones (hetero-auxin) but through abnormal growth or lethal effects of the host disturbs normal production, activation and transport of auto-auxones (plant auxins)". Link and Eggers (1941), using an ether extraction method in conjunction with the *Avena* test, presented evidence to show that there was a significantly greater amount of growth-substance present in gall tissue than in control tissue. In discussing this result they stated that "in addition to auxones, including auxins furnished by the parasite, the host cells—local and distant—also contribute to the hyperauxony of the affected organ".

Locke, Riker and Duggar (1938) showed that virulent cultures of *B. tumefaciens,* when inoculated into tomato stems above the inoculation points of an attenuated strain (which by itself only produced slight stem swelling) induced strong gall formation at the points of entry of the latter. These workers suggested therefore, that some substance from the tissue inoculated with the virulent strain, diffused down through the stem and stimulated cell division at the inoculation points of the attenuated strain. In similar experiments, hetero-auxin in lanoline paste applied in high concentration (30 mgm. per gram of paste), either failed to diffuse in quantity to the inoculation points of the attenuated culture or at least produced little effect there, as there was no significant increase in cell proliferation. A point of interest was that the stimulating effect of the virulent culture on gall development at the point of inoculation of the weak strain, was not exerted as markedly in the upward direction (Riker, 1940). This is perhaps only to be expected in accordance with the polar movement of growth-substance when in physiological concentration. The non-polar upward and downward movement of hetero-auxin in stems (see Brown and Gardner, 1936) apparently occurs when concentrations of this substance are high. The relative failure of hetero-auxin to induce increased cell proliferation, either at the point of inoculation of the attenuated strain or at any other point on the stem of tomato, is interesting in view of the results

of Brown and Gardner (1936) for French bean. The difference may be due, in part, to the host or to the mode of application. Locke, Riker and Duggar (1938, 1939*b*) agreed with Leonian (1937) that growth-substance was more likely to be a product of host cells under the influence of bacterial action rather than a direct bacterial metabolic product. They found that it was not possible, however, to distinguish between growth-substance from the foliage of the normal plant and from that in Crown Gall culture. The growth-substance extracted from the plant resembled indole-3-acetic acid in its sensitivity to acid and alkali. In this connection it may be noted that in recent papers Lefèvre (1938), and Haagen-Smit, Leech and Bergen (1941), have reported the presence of indole-3-acetic acid in higher plants.

*Gall Formation Due to Growth-substance Produced Both by Parasite and by the Host.*

Link, Wilcox and Link (1937) and Link and Eggers (1941), whose work has been reported in the preceding two sections, incline to the view that growth-substances are produced both by the parasite and by the plant. Each source contributes to the significantly greater amount of active substance which they found to be present in galled tissues.

*View that growth-substances of the Auxin and Hetero-auxin Type are not Important in Gall Formation.*

Riker, Birch Henry and Duggar (1941), using quantitative ether extraction methods, re-examined the question of growth substance content of inoculated and control tissue. In these experiments, involving a large number of *Avena* tests, they failed to find any significant difference between the auxin content of control and inoculated tissue. This held true over periods ranging from 1 to 16 days after inoculation. Similarly, no significant difference could be detected between the amounts of auxin diffusing from stems bearing galls and from control stems. A further interesting point was that when comparable plants were inoculated and grown at temperatures at which gall formation occurred (27°C.) and at which it did not occur (31°C.), there was found to be no significant difference in auxin production.

They therefore concluded that the gall formation was not due to the production of hetero-auxin or similar growth-substances as measured by the ether extraction and *Avena* technique. These negative results led them to examine the production of other active substances including vitamin $B_1$, biotin, flavin and pantothenic acid, in relation to the cell-stimulating property of the parasite. A preliminary note (Birch Henry, Riker and Duggar, 1942) indicates that vitamin $B_1$, as assayed by the *Phycomyces* method does not appear to have any causal role in Crown Gall development.

It should be pointed out that the experiments of Link and Eggers (1941), in which they showed that there was a significantly greater amount of growth-substance present in galled tissue, were on a comparable scale to those of Riker, Birch Henry and Duggar (1941). Since the results of these two groups of workers are diametrically opposed, it appears that the question as to whether there is present a greater amount of growth-substance in Crown Gall tissue, must be left open.

A consideration of the above lines of evidence indicates that the high hopes of the solution of the Crown Gall (cell proliferation) problem in terms of the production of hetero-auxin or similar growth-substance by the parasite, have not been realized. There are, however, very strong indications that some growth-substance mechanism is involved in infected plants. The most promising approach now, in the opinion of the writer, would be through a more thorough study of auxin and "food factor" relations in the normal and infected plant. The trend of modern research on the growth-substance theory, while maintaining the necessity of auxin for growth, indicates that even in the presence of adequate auxin, a second "food factor" is necessary. Schneider (1938) has shown this to be sugar in the case of *Avena*. It is possible, therefore, that the pathogenicity of the Crown Gall organism is related to its ability to supply some relatively simple "food factor" in the course of its metabolism. The local accumulation of this in addition to the usual "food factor" may upset the normal balanced growth at the point of entry of the parasite, leading to overgrowth. The work of Locke, Riker and Duggar (1938), in demonstrating that inoculation of tomato stems with a virulent strain, stimulated gall formation at the point of inoculation with an attenuated culture, may yet prove to be important in relation to such a "food factor" hypothesis.

### 2. Other Overgrowth Conditions Caused by Parasites.

Data on other overgrowth conditions caused by strongly parasitic organisms is at present meagre and in most cases has not advanced beyond the preliminary stage. Link, Wilcox and Link (1937) reported in the case of *Ustilago zeae,* causing Smut Galls on maize, and *Taphrina deformans* causing Peach Leaf Curl, that a substance giving tests for hetero-auxin could be extracted from the organisms. Moulton and Link (1940) in a short abstract, state that *Ustilago zeae* grown on a tryptophane-free medium is capable of producing "auxins". Link and Eggers (1941) refer to Moulton's work (Thesis 1941) on Smut Galls of Maize and state that, using delicate methods of extraction, more "auxin" was obtained from gall tissues than from healthy tissues. "Auxin" as used here appears to be used as a general term meaning growth substance.

## Overgrowth due to Controlled Parasitism (Symbiosis).

### Root Nodules of Leguminosae.

The root nodules of Leguminosae on account of their important relation to agricultural practice have attracted a great deal of attention from scientists. It is only recently, however, that attention has been focussed in greater degree on the mechanism of cell proliferation inducing the nodule formation. The condition is of interest to the pathologist because it lies on the border line of parasitism. It has long been debated whether the relationship of the nodule organism to its host plant constitutes an instance of true symbiosis or an instance of controlled parasitism. The work of Brenchley and Thornton (1925), in which they showed that when *Vicia faba* was grown on a boron deficient solution the bacteria attacked the host cells, followed by the researches of Thornton (1930*a*), in which he demonstrated that parasitism develops in the case of inoculated lucerne seedlings placed in the dark, swung opinion to the viewpoint of controlled parasitism. Under normal conditions, the organism and the plant live in equilibrium and the advantages are mutual.

Two of the fundamental problems involved are, firstly, how the bacteria enter the plant and, secondly, how the nodule is formed, that is, how the bacteria bring about the proliferation of cells. In order to understand how these occur it is first desirable to know something of the normal course of root infection. This has been clearly described and figured in the case of lucerne by Thornton (1936) and will be outlined here. The usual avenue of infection is via the root hairs and the earliest stage detected by Thornton was the formation of a small colony of the bacteria close to the distal end of the root hair, the tip of which usually becomes coiled into a short spiral. Infection takes place only in this deformed region, this deformation being apparently a necessary prelude, and manifests itself by the formation of a thread of bacterial zoogloea passing down the interior of the root hair. Nodules become visible to the naked eye within twenty-four hours after infection of the root hair. Nodules of clover and lucerne consist of a mass of proliferating cells mostly in the cortex but penetrating also into the pericycle (Thornton, 1930*b*). The central cells swell and become infected with bacteria and by the time that the nodule is a week old the cytoplasm of the infected cells in the central region, becomes filled with bacteria. Thornton and Rudorf (1936) state that there is present at the distal end of a healthy legume nodule, a cap of meristem cells by whose continued division the nodule grows in length. This meristem is also concerned with the differentiation of the lateral endodermis and vascular strands.

Sufficient has now been given of morphology and structure to allow us to consider possible mechanisms of the formation of the nodule. It was discovered as early as 1900 by Hiltner that filtered secretions of the bacteria could induce deformation of the root hairs indicating that the organism excreted some active substance into its medium. Molliard (1912) working with rhizobia from bean, recorded the fact that sterile bacterial secretions could cause abnormal growth effects in roots of *Pisum*. He found that roots of peas allowed to grow in such solutions were retarded in growth, showed increased cell division, radial enlargement in the pericycle and deformation of cortical cells as compared with control roots which had grown in non-inoculated media. Molliard concluded that the organism excreted some active substance into its media which brought about conditions similar to those whoch obtained in actual infection.

Secretions from *Rhizobium meliloti* were shown by Thornton (1936) to stimulate both the production and growth in length, and deformation of the root hairs of lucerne. The substance was non-specific in its action, in that filtrates of cells from one cross inoculation group, deformed root-hairs of plants belonging to another group (McCoy, 1932). Its action in increasing production and length of root hairs would bring it into the class of growth-substances. As Wilson (1940) points out, the deformation of the hair on the basis of hormone in the filtrate is not so easily explained. One would not expect differential rates of growth as the concentration of the hormone should be the same on all sides of the root hairs. An interesting point arises here in that this substance stimulates growth in length of root hairs; all growth-substances so far tested have an inhibiting effect on elongation in root tissue. The possibility must be considered that root hairs are organized in a similar fashion to and consequently react in a similar way to the cells of coleoptiles on the application of growth substance. There appears, however, to have been no investigations on the effect of auxins on root hairs.

Thimann (1936, 1939) was the first to examine the question of the mechanism of nodule formation in the light of the auxin theory of growth. He postulated the following series of events after the bacteria enter the root tissues:—Small amounts of an auxin, among other substances, are produced in the course of bacterial metabolism, especially when the organisms attack carbohydrate or protein in the invaded cells. This substance causes enlargement of the cells in which it is produced and also being readily diffusible enters the pericycle behind the cortical tissue inhabited by the bacteria and there stimulates growth and division giving rise to the first stages of a lateral root initial. In the presence of continued auxin production, however, this potential lateral root is prevented from elongating; instead its cells increase in size isodiametrically while certain of the

uninfected cells are stimulated to division by auxin diffusing out of the infected area. In this way he considers " a shapeless mass of parenchymatous tissue is produced which is essentially a lateral root prevented from elongating." The evidence on which Thimann based his hypothesis was as follows:—(*a*) The auxin activity of young nodules (2 to 3 mm. in diameter) was of the order of 10 to 12 plant units per nodule for three hours' diffusion. (*b*) Auxin was demonstrated to be present not only in the apical meristematic region but also in the basal portion which consists of infected cells. (*c*) Application of auxin to very young lateral roots resulted in complete inhibition in growth elongation, swelling due to radial elongation of cortical cells, together with divisions in the cambium and pericycle. (*d*) Indole-3-acetic acid was produced in culture media containing tryptophane in which rhizobia had grown. Thimann's general conclusions were that the course of nodule formation involves the production of indole-3-acetic acid by the bacteria which probably liberate it in the course of breakdown of tryptophane present in the nodules. He cites the work of Molliard (1912), noted earlier, pointing out that the effect of indole-3-acetic acid on the root is exactly the same as that of the sterile filtrate tested by Molliard.

Wilson (1937, 1940) discussing Thimann's work indicated that the idea of indole-3-acetic acid being the long sought stimulant was attractive, but rightly pointed out that more experiments were required. He also considered that further evidence was necessary to determine whether secretions from the root nodule bacteria would cause a response similar to that obtained when synthetic hetero-auxin was applied. Regarding this last point it would appear that the work of Molliard (1912) demonstrates, in the case of *Pisum* roots, effects of filtrates which are similar to those induced by auxins. However, if Thimann's hypothesis is to apply generally, it is still necessary to demonstrate nodule-forming phenomena, other than root curling, when bacterial secretions are applied in the case of lucerne, clover, etc. A further difficulty which may be mentioned is that many investigators believe that the structure of the nodule does not indicate a modified lateral root as Thimann states. Fred, Baldwin and McCoy (1932) discuss the evidence for and against this conception of its nature, and conclude:—"It (the root nodule) is distinctly not a modified lateral root, for it has no central cylinder, root-cap nor epidermis. Furthermore, it does not digest its way out from the cortex of the main root but remains covered with a considerable layer of cortical parenchyma."

It has been shown by a number of workers, Link (1937), Chen (1938), Thimann (1939), and Georgi and Beguin (1939) that various species of *Rhizobium* produced indole-3-acetic acid in culture. The position has been complicated, however, by the fact that both effective and ineffective strains of nodule bacteria

and also organisms which live as contaminants in the nodules, all produce comparable amounts of growth-substance. Thus Chen (1938) found that effective and ineffective strains of clover bacteria when growing vigorously in liquid culture produced similar amounts of growth-substance as assayed by Went's split pea test (Went, 1934). Old laboratory strains that had lost the ability to infect and produce nodules were, however, found to produce less. Georgi and Beguin (1939) reported that four species of *Rhizobium* in culture produced indole-3-acetic acid. According to them the ineffective strains appeared to be more efficient growth-substance producers than the effective strains. *B. radiobacter*, a contaminant living in the nodules, was also found to produce growth-substance. These workers consequently question whether indole-3-acetic acid plays a causal role in nodule growth.

Chen, Nicol and Thornton (1940) appear to accept the view that initiation and maintenance of the apical meristematic cap of the nodule is due to growth-substances produced by the bacteria. Discussing the difference between nodule production by effective and ineffective strains, they state that the arrested growth in the ineffective nodules is due to the stopping of cell division in the apical cap, which in turn would appear to be related to the early arrest or decrease in growth of the contained bacteria. The decrease in bacterial growth might be taken to indicate that less growth-substance would be produced and consequently less cell division would occur. These workers made the interesting observation that juice from roots (of peas and soy beans) bearing effective nodules gave better growth for the organism in culture than did control juice, and that juice from roots of plants with ineffective nodules gave growth significantly poorer than control juice. Chen, Nicol and Thornton (1940) suggest that the stimulating effect was possibly concerned with the products of nitrogen fixation. It seems possible, however, that it may be some active growth-substance which is produced in the plant as a reaction to infection by effective strains and that as it can stimulate bacterial growth it may also be concerned in the cell proliferation.

Link and Eggers (1940), and Link, Eggers and Moulton (1941) present evidence to show that more growth-substance (as assayed by the *Avena* test) can be obtained by ether extraction from nodules of kidney bean and garden pea, and to a lesser extent for soy bean, than from denodulated roots, while less still could be obtained from roots grown in sterilized quartz sand. They conclude from this that nodules of bean, soy bean and pea have greater and different auxin contents than the roots which bear them and that these in turn have greater auxin content than the roots when grown in sterilized substrates. This represents a more cautious view than that expressed earlier by Link

(1937) when he stated that indole-3-acetic acid was one of the chemical agents, if not the primary one, responsible for the formation of nodules in certain leguminous plants. Thimann and Schneider (1939) although not comparing nodules with denodulated roots, pointed out that nodules of *Phaseolus vulgaris* were very active in producing growth-substance as tested by the quartered coleoptile test.

In conclusion we may say, that in the case of root nodules of Leguminosae, there appears to be no doubt that the bacteria secrete some chemical substance which causes the increase in length and deformation of root hairs in nature and also under laboratory conditions. According to Nicol (1938) the chemistry of this substance is still obscure. Its physiological activity, however, would appear to put it in the class of growth-substances. The mechanism inciting cell proliferation in the nodule is still in doubt. The hypothesis that indole-3-acetic acid (produced by bacterial metabolism in the plant) is causally related to cell proliferation is not favoured by the balance of evidence. Nor does it appear likely that the substance, referred to above, which is responsible for root hair deformation, can be the cause of the overgrowth.

There appears to be no conflict of evidence so far on the question of heightened growth-substance content in the nodules, and it therefore appears likely that a hormone mechanism is involved. This increased growth-substance would appear to be developed by the plant as a response to the bacterial infection.

Further research on the identity of the stimulating substance for "effective" nodule bacteria found in the roots of pea and soy-bean, will, it is believed, prove helpful in the solution of the problem.

## Adventitious Root Formation.

Adventitious roots develop as a host reaction in tomato and certain other plants following infection by *Bacterium solanacearum, Bacterium tumefaciens, Aplanobacter michiganense* and *Fusarium bulbigenum* var. *lycopersici.* Such disease-induced roots, which generally show on the stem surface as small nodular projections, are to be distinguished from those which may develop on healthy plants under glasshouse conditions.

Hunger (1901), Smith (1914, 1920), Bryan (1915), and Grieve (1936, 1940) have reported on their occurrence in the case of *B. solanacearum.* In this disease the adventitious roots on tomato plants develop characteristically over several internodes along the path of the primary bundles, spreading later to the secondary tissues. Plants which show the reaction include tomato, African Marigold, garden Nasturtium and Sunflower (Grieve, 1940).

The presence of induced adventitious roots in plants such as Balsam, tomato and Paris Daisy infected with *B. tumefaciens* has been recorded by Brown (1929), Link, Wilcox and Link (1937) and Locke, Riker and Duggar (1938). Grieve (1940) pointed out that tomato plants artificially inoculated with *B. tumefaciens* show fewer adventitious roots, which are also more localized in distribution, than is the case for *B. solanacearum*. These differences appear to be related to the different distribution of the bacteria in the two diseases. Again, adventitious root formation in tomato, arising from infection with *A. michiganense*, ranges from abundant to scanty. Smith (1914, 1920) first reported their occurrence but found them to be relatively few in number. He concluded that this was due to the fact that this phloem parasite rapidly invaded the root primordia.

Fisher (1935) first mentioned root initials as being associated with infection by *Fusarium lycopersici* and this observation was confirmed by Wellman (1941).

That a stimulus of some sort was involved in adventitious root formation in the case of *B. solanacearum* was envisaged by Hutchinson (1913) and Smith (1920). Grieve (1936) pointed out the similarity of the reaction to that induced by ethylyene and carbon monoxide gases (Crocker *et al* 1932, Zimmerman *et al* 1933), and indole-3-acetic acid (Hitchcock, 1935a). Locke, Riker and Duggar (1938) noted this also for *B. tumefaciens* infections and Wellman (1941) for Fusarium Wilt.

The extended development of the adventitious roots along the vascular bundles in the case of tomato and African Marigold plants infected by *B. solanacearum*, made these plants suitable hosts for an examination of the mechanism of adventitious root formation. The disease differs from Crown Gall in that it is possible to ascertain the relation of the bacteria to the developing roots. Thus Grieve (1940) pointed out the following relations of *B. solanacearum* to the induced roots:—

(*a*) Adventitious roots frequently commenced to develop ahead of advancing columns of bacteria in vessels.

(*b*) Development of the root primordia, once initiated, continues to the stage where the root becomes visible as a nodule at the surface of the stem, even though the bacteria during this period gradually block all the vessels nearest the incipient root.

(*c*) Where vessels are rapidly filled with bacteria, no adventitious roots develop.

This histological study also established the fact that the action of the bacteria, in the case of tomato at least, was not always excited from a distance as Hutchinson (1913) and Smith (1920)

believed. Nevertheless it strongly suggested that the bacteria were inducing the roots either directly by the production of some stimulatory substance or indirectly by their interference with the metabolism of the plant.

Grieve (1936, 1939, 1940) reported the extraction of a physiologically active substance from culture media containing glucose, peptone and mineral salts in which the bacterium was grown. This extract in crude form gave positive tests for hetero-auxin and induced adventitious roots on application to tomato and African Marigold.

Experiments with virulent and non-virulent cultures of *B. solanacearum* showed, however, that they produced approximately equal amounts of growth-substance. The same held true for pathogenic and non-pathogenic cultures of *A. michiganense*, *B. tumefaciens* and *B. flaccumfaciens*.

The suggestion that *B. solanacearum* produced growth-substance by acting on naturally occurring or artificially introduced tryptophane in the xylem was experimentally tested but no evidence of such production was obtained. This led the writer to doubt whether the bacteria initiated the adventitious root primordia through the medium of hetero-auxin production, and led to the formulation of the view that the mechanical blocking by the bacteria might induce the effect through disturbance of the normal hormone movement.

Experiments involving cutting and blocking of the xylem with inactive substances gave results which supported this view. Ether extractions of growth-substance which were assayed by the *Avena* test, showed, however, no significant difference in the amounts present in comparable healthy and infected plant parts.

Further experiments are required to check this, but the writer is of the opinion that significant auxin differences are not necessary, since the amount of auxin necessary to induce adventitious root formation *in vivo* is minute. One must also envisage the using up of some of this auxin in bringing about the root formation.

The problem of adventitious root formation in the case of *B. tumefaciens* is bound up with the general problem of gall formation and the conclusions reached there apply. The evidence of Locke, Riker and Duggar (1938, 1939), of Riker, Berch, Henry and Duggar (1941) and of Grieve (1940) makes it appear reasonably certain that hetero-auxin formation by the parasite is not causally related to adventitious root formation. Opinion also is still divided on the question of relative amounts of auxin in galled tissues as compared with comparable healthy plant parts.

With regard to *A. michiganense* no investigation appears so far to have been made, apart from the observation that pathogenic and non-pathogenic cultures of this organism produce approximately the same amounts of growth-substance (Grieve, 1940).

Wellman's paper on Fusarium Wilt (1941) merely reported adventitious root formation. The course of the disease here is not unlike that of Bacterial Wilt (*B. solanacearum*) in so far as symptoms are concerned and should prove a suitable subject for research on the mechanism of adventitious root formation.

It would be interesting to know whether the toxin produced by *Fusarium bulbigenum* var. *lycopersici*, has any bearing on the reaction.

## Growth Movements—Epinasty and Hyponasty of Leaves.

Epinasty of leaves seems to be generally associated with adventitious root formation, both occurring as symptoms in the same disease, e.g., plants infected with *B. solanacearum* (Hunger 1901, Smith, 1920), *B. tumefaciens* (Locke, Riker and Duggar, 1938), and *Fusarium bulbigenum* var *lycopersici* (Wellman 1941). Leaflet epinasty has also been recorded as a primary symptom in the case of Rose Wilt Virus (Grieve, 1941) and there is a strong tendency toward it in young tomato plants infected with tomato Spotted Wilt. Hyponasty of leaves has been observed in plants infected by *Bac. phytophthorus*.

The only investigations so far available on leaf epinasty induced by parasites are those by the author (Grieve, 1936, 1939, 1940, 1943).

The reaction in the case of infection by *B. solanacearum* was shown to be an irreversible growth reaction and invasion of one lateral trace sufficed to induce it.

An experimental investigation of possible causes of the response showed that toxin production, ammonia production and hydrogen-ion effects were not involved. Experiments on mechanical blocking gave largely negative results (1939), although in later experiments (1940) there appeared to be some evidence which favoured it.

A growth-substance which gave the tests for hetero-auxin, was found to be produced in media in which the bacterium had grown, and this substance induced epinasty in leaves of young tomato plants.

No significant difference between the growth-substance content of comparable portions of infected and control stem parts of tomato plants showing leaf epinasty could be detected by the

ether extraction method. Examination of the hormone distribution in the upper and lower halves of reflexing petioles has, however, shown a significantly greater amount in the upper halves. In normal petioles there is a greater concentration in the lower half (Grieve, 1943).

In 1939 the writer made the suggestion that the normal petiolar position was conditioned by a balanced hormone mechanism and that the disturbance of this would lead to epinastic response. The results given above show that the growth reaction of epinasty is associated with an increased concentration of auxin towards the upper surface. This redistribution of growth substance, which has also been demonstrated to occur in the case of leaf epinasty associated with Crown Gall, is induced by the bacteria. No definite conclusion as to how the redistribution of growth substance in the basal part of the petiole is effected, can yet be made. As the writer pointed out (1939), however, the balance of the normal growth controlling mechanism at the base of the petiole is very delicate. This is reflected by the fact that ethylene in one part in 10 million of air, as well as very small amounts of growth substance from bacterial cultures, suffice to disturb it. It is not unlikely, therefore, that even a small stimulus from the invading organisms can initiate a chain of reactions leading to the redistribution of hormone with consequent epinastic response.

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# Art. VI.—*The Geology of Warrnambool.*

By EDMUND D. GILL, B.A., B.D.

[Read 11th June, 1942; issued separately 1st October, 1943.]

## Abstract.

A coastal strip of over two miles wide of consolidated Pleistocene calcareous dunes overlies a bedrock of horizontally-bedded Miocene marine limestone. Inland from the dunes is a plain of ?Pliocene olivine basalt overlying siliceous fluviatile sands and gravels, which rest on the bedrock limestone. Holocene shell beds prove a relative land uplift of at least 14 ft. 6 in. Tuff from the extinct Tower Hill volcano overlies a great deal of the area

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The Pliocene Basalt.
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## Introduction.

This paper presents the results of a study of the area comprehended within the boundaries of the city of Warrnambool. A reconnaissance was made of the country within ten miles of the city to establish the general relationships of the formations appearing in the area of detailed study.

## The Miocene Limestone.

The bedrock of the Warrnambool District consists of Miocene marine sediments of Barwonian age in thick beds lying horizontally. The strata which outcrop are highly calcareous sediments, sometimes soft and friable, but often considerably indurated with secondary calcite. They form part of the Miocene beds which extend across the south-western part of Victoria into south-eastern South Australia.

The presence of Miocene limestone at Warrnambool has been noted by Wilkinson (1864-5), and in a list of Tertiary fossils Dennant and Kitson (1903) record "*Pecten foulcheri*, *Magellania insolita*, *Magasella woodsiana*, and *Lovenia forbesi*" from that city. Murray (1887, p. 104) refers to Miocene marine beds on the Hopkins River.

The writer has found fossils on the northern and south-eastern rim of the Tower Hill crater, also at the outcrops of limestone marked on the map (fig. 2); behind the tennis court at Woodford; in a quarry on the west side of the bridge near the State School at Curdie's River; in the cut for the drainage of Lake Gillear; in a road cutting on the south side of the Cobden-Colac road on the west side of the bridge over the creek which is a branch of the Curdie's River, and in a road cutting on the hill on the Cobden side of Jancourt.

In Western Victoria the Miocene sediments attain a considerable thickness, but at Warrnambool their thickness has not been proved. A bore described by Griffiths (1891) went through dune rock and then Miocene limestone to a depth of 398 feet, where it was still in the latter formation. Many bores have been put down for water in the district, but the deepest other bore of which I have knowledge is one at Wangoom which was sunk to a depth of 170 feet, all of which was marine limestone. At Portland, a bore put down in the Botanic Gardens traversed 2,265 feet of Tertiary rocks without reaching the underlying strata.

The Miocene beds are very fossiliferous, although the preservation is usually very poor. *Lovenia forbesi* and *Ditrupa* appear to be the commonest fossils, the latter often occurring in bands closely crowded with the tests. Brachiopods, pelecypods, and bryozoa are common in the river section on the west bank of the Hopkins River north of the bridge (fig. 1). Dr. F. A. Singleton kindly examined a collection of fossils made by Mr. George Jorgensen and the author. He stated that they indicated a Barwonian age, but on the material collected a closer determination of age could not be made. Mr. Parr kindly examined some material collected from the Miocene limestone at Warrnambool, but the foraminifera were too poorly preserved for determination.

## The Pliocene Basalt.

Basalt is seen in the north-east corner of the city of Warrnambool (fig. 1), but this is only the edge of a great lava plain which stretches away to the north (Hills, 1939). It is mostly vesicular and somewhat decomposed, but parts of the flow are dense and comparatively fresh, being of a light bluish colour in hand specimen. A sample collected from the road cutting at the gate of Mr. Wall's property about half a mile north-west of the

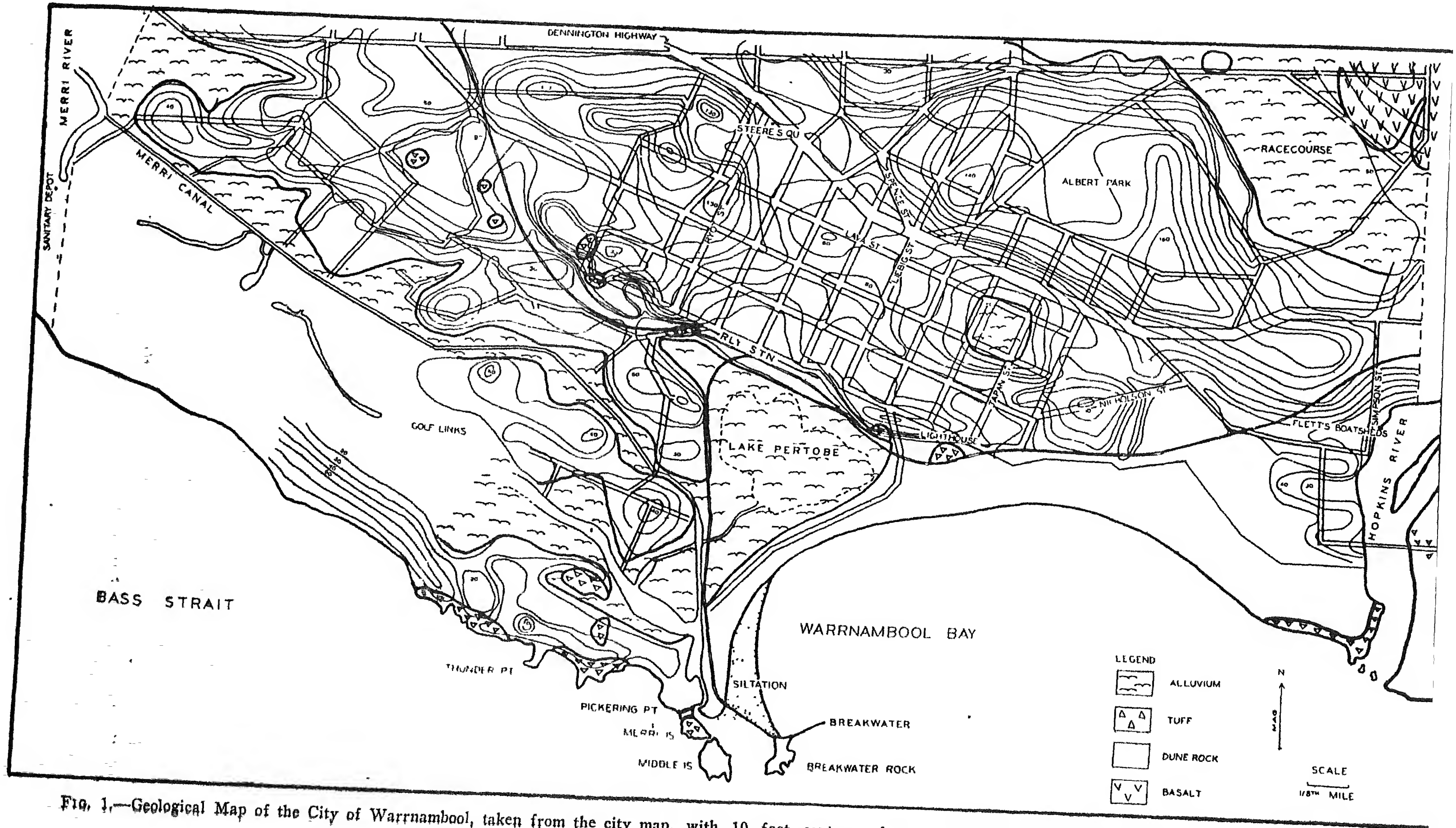


FIG. 1.—Geological Map of the City of Warrnambool, taken from the city map, with 10 feet contours from a sewerage map kindly loaned by the City Engineer, Mr. G. M. Chisholm, B.C.E., C.E.

Wollaston Bridge (fig. 2) has been determined by Dr. A. B. Edwards as an olivine basalt of the Footscray type. The basalt has been used as a building stone in a few instances at Warrnambool, but its chief economic use is for road metal and screenings.

The following evidence has a bearing on the age of the basalt:

1. The flow overlies extensive post-Barwonian fluviatile deposits (fig 2). Current-bedded sands and gravels have been quarried to a depth of 15 feet on the Wollaston Estate, where basalt superimposes them. Remains of sticks were obtained from a thin clay seam interbedded with the gravels.

2. The pre-basaltic terrain is a diversified one. For instance, sections along the banks of the Merri River at Woodford show a thickness of basalt of about 20 feet, but a boring record ¼ mile away near the stone house of Mr. Ben Morgan shows 80 feet of decomposed basalt, 15 feet of clay, and so to the bedrock. A bore at Cudgee Milk Depot proved only 9 feet of basalt, whereas there are basalt quarries nearby. The basalt is seen to occupy small valleys at White's Lane and the Racecourse, but ¾ mile behind the Half-Way Hotel towards the Merri River, a bore has shown 60 feet of decomposed basalt to be present.

3. To the north and north-east of Warrnambool the basalt flow which reaches that city (fig. 2) is covered by another flow of more recent date. On Mr. Good's property at Winslow, the following deposits were bored:

| | | |
|---|---|---|
| Decomposed basalt | .. | 30 feet |
| Tuff .. | .. | 2 ,, |
| Fresh basalt | .. | 30 ,, |
| Yellow clay .. | .. | 20 ,, |
| Marine limestone | .. | — |

A bore on Mrs. McNamara's property near the State School at Cooramook traversed:

| | | |
|---|---|---|
| Basalt .. | .. | 80 feet |
| Gravel .. | .. | 15–18 ,, |
| Dense basalt | .. | 4 ,, (not pierced) |

A bore ¼ mile off the Ellerslie Road towards Framlingham went through:

| | | |
|---|---|---|
| Basalt .. | .. | 124 feet |
| Coarse gravel | .. | 15 ,, |
| Very dense basalt | .. | 25 ,, |
| Black clay .. | .. | 20 ,, |
| Yellow clay | .. | 5 ,, |
| Marine limestone | .. | — |

A similar series of deposits was traversed by a bore on the Aborigines' Reserve at Framlingham. The Hopkins Falls on the Hopkins River are apparently due to the river flowing off the younger flow on to the older.

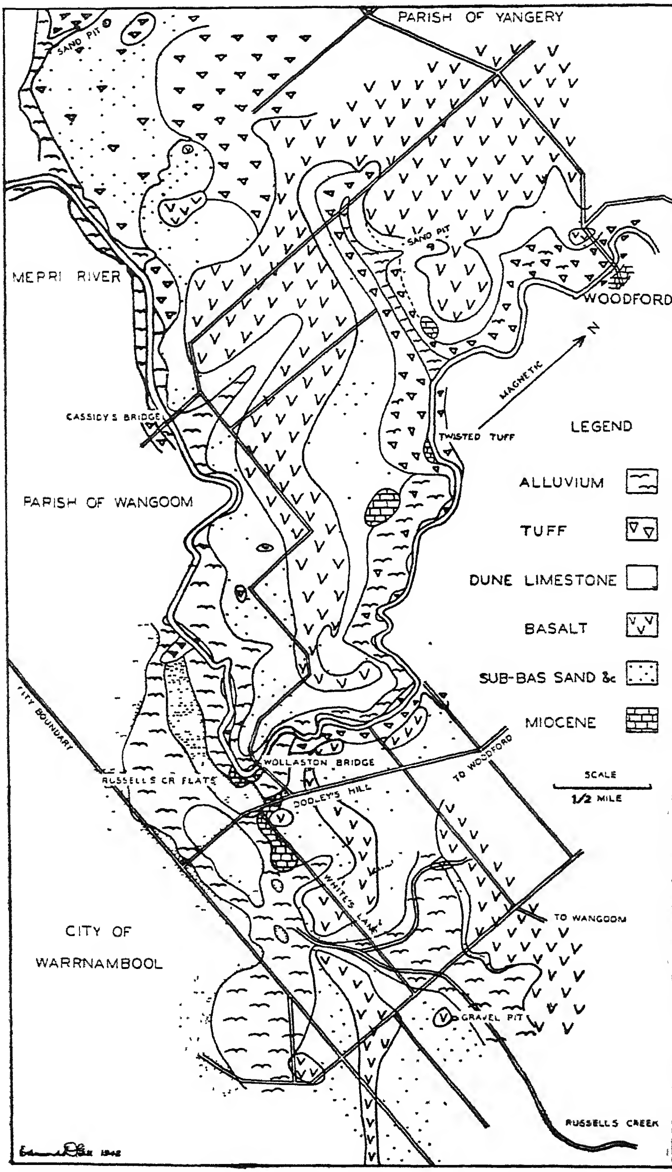


Fig. 2.—Geological Map of an area north of the City of Warrnambool, based on plans of the Parishes of Wangoom and Yangery.

4. Consolidated dune limestone (Pleistocene) rests on the eroded surface of the basalt. This can be seen in a road cutting in White's Lane (fig. 3) which is the furthest point inland at which the dune rock is found, and so presumably a remnant of the oldest line of dunes. As it is believed that the dune-building began with the Ice-Age (= Pleistocene), it may be inferred that because the dune rock overlies the eroded basalt, that the basalt is not younger than Upper Pliocene.

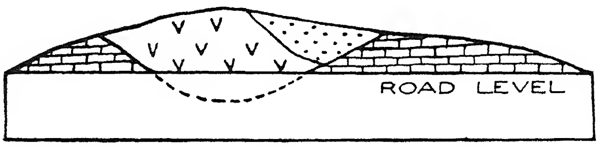


FIG. 3.—Road Section at White's Lane, north of Warrnambool, showing consolidated dune rock resting on the eroded surface of the basalt.

5. The basalt has been widely dissected by streams (fig. 2), and the records of the very numerous borings made for water in the district show the flow to be mostly in a state of decomposition. Buckshot gravel is plentifully developed over the basalt, tens of thousands of tons of this material having been used for road-making in the Warrnambool shire.

Thus the decomposition of the basalt, its dissection by streams, and the big development of buckshot gravel all indicate an older rather than a younger age for it.

From the evidence for the age of the basalt outlined in this section of the paper it will be seen that this lava flow is post-Miocene in age and pre-Pleistocene, and may therefore be referred to the Pliocene period.

## The Pleistocene Dunes.

### 1. Extent and Character.

Murray (1887, p. 131) writes, "The sand rocks of Post-Tertiary age along portions of the coastline, as at Warrnambool and Cape Otway, are aerial deposits formed by the action of the wind blowing sand into dunes and hillocks which subsequently consolidated owing to the presence of calcareous matter derived from the shell fragments associated with them. These rocks have been partly denuded, and their materials are now in course of fresh distribution by every wind." Etheridge (1876) and Pritchard (1895) have also given a general account of these dunes. Rawlinson (1878) and Mahony (1917) made observations on the Warrnambool dunes, the latter giving a chemical analysis of the dune material.

The dunes are a conspicuous feature of the coast from some distance east of the Hopkins River as far as Port Fairy which is 16 miles west from Warrnambool. The city of Warrnambool is built on the dune rock. In this paper the consolidated dune sandstone (if one thinks of its texture) or limestone (if one thinks of its chemical composition) is treated separately from the loose sand of the present mobile dunes. The former are considered to be Pleistocene in age, while the latter are of Holocene age.

The consolidated dune rock is extensively developed at Warrnambool where it is very thick and stretches inland for $2\frac{3}{4}$ miles At this distance inland the Merri River runs for over 3 miles parallel to the coast, flanked on one side by basalt and on the other by dune rock. At Albert Park the dune limestone reaches a height of over 160 feet above sea level. Mr. Keith McCrabb informs me that bores put down at his own place (46 Spence-street) and at the Paragon Cafe in Liebig-street, traversed 96 feet and 65 feet respectively of dune rock. Mr. Bruce informs me that a bore put down at the premises of Bruce and McClure, Lava-street, proved a depth of 80 feet of dune rock. All these places are about 70 feet above sea level. A bore put down at the Sanitary Depot near Levi's Point penetrated 110 feet of dune sandstone before reaching the marine limestone which was bored a further 10 feet. The location of the bore is 43 feet above sea level, so the sandstone occurs to a depth of 67 feet below sea level at this point which is about $\frac{1}{4}$ mile from the coast.

The Admiralty Chart of the coast shows that the shore platforms, which are formed of consolidated dune sandstone and shallow waters, extend seawards for about a quarter of a mile. Seven hundred yards out from the mouth of the Hopkins is the "Hopkins Reef" which is of the same rock. A line of section taken east from Pickering Point through Breakwater Rock traverses half a mile of island and platforms before entering moderately deep water. Taking into account the shore platforms (Plate II., fig. 4), there is a width north and south of 3 miles of dune rock at Warrnambool. The presence of rock stacks and the fact that the pebbles washed up on the beach are all dune rock shows that it stretches out to sea for some distance. In some rock stacks aeolian bedding can be clearly seen running down as far as visibility extends below the low water level. Thus, stretching round the coast for some 20 miles there are these dune deposits extending inland from one to three miles, and on the evidence of bores and coastal features occurring to a depth well below the present sea level.

The material of the dunes is predominantly calcareous, consisting of comminuted shells, echinoid tests and polyzoa, and of foraminifera. Three published analyses give the percentage

of carbonate of lime as 92·43 (Officer, 1891), 86·25 (plus 6·64 of magnesium carbonate—Mahony, 1917), and 92·85 (Coulson, 1940, p. 330). In a cutting on the road to Cassidy's Bridge, 200 yards north of the Warrnambool-Dennington highway, a quartzose sandy soil can be seen under 18 inches of tuff. This quartzose layer is probably due to leaching of the limestone in which there is a small percentage of quartz. Crocker (1941) so explains similar horizons in the South Australian dunes.

The dune rock is sometimes comparatively soft, and friable. The rock, when even and compact, is used for building purposes, being sawn into blocks with ordinary steel saws. The consolidated dune limestone is mostly traversed by calcitic seams sometimes 3 inches wide. In places the sandstone is so indurated that it is glassy and splintery when broken, as, for example, at the east end of Albert Park where it is crushed for road-making purposes.

Caves are common in the dune limestone as they are in the Miocene marine limestone. In the excavations for the sewerage system several more of these caves were located. Belvedere Cave, which is a few hundred yards upstream from Flett's boatshed on the Hopkins River is in Miocene limestone and possesses the remains of stalagmites and stalactites. Many other caves are known in the district (*vide* Bonwick 1858, and Osburne 1887).

The aeolian bedding in the dune rock at Warrnambool shows that at the time of their formation the prevailing winds were south-west as they are now (Rawlinson, 1878). This is shown also by the disposition of the tuff deposits. The windward slopes of the dunes are 10 to 15 degrees, and the leeward slopes 30 to 33 degrees.

Another conspicuous feature of the dune sandstone is the presence of buried soil horizons such as noted previously at Warrnambool by Murray (1887, fig. 45) and Archibald (1894), and at Portland by Coulson (1940). The soil layers vary in thickness from 2 feet to a few inches, and can best be seen in the cliff sections along the coast, especially in the vicinity of Thunder Point where five layers can be seen counting the one under the tuff. The lowest (Pl. II., fig. 2) is 3 feet thick and can be followed for ½ mile round the cliffs, where it ultimately fades out in an "unconformity" which is only a cross-bedding. Such unconformities are due to the planation of an older dune which had been consolidated, and the building of a later one on the eroded surface. An unconformity (Pl. II., fig. 5) thus represents a break in the process of dune-building as does a soil horizon. Three other soil horizons can be seen close together at Thunder Point (Pl. II., fig. 3), and a fifth under the Holocene tuff which caps the cliff (Pl. II., fig. 7). Soil horizons can again be seen at Pickering Point, Ryot-street road cutting,

Simpson-street road cutting, Nicholson-street Quarry, and Albert Park Quarry. That at Pickering Point as well as some noted in sewerage excavations have been indurated by the deposition of calcareous matter in them. Further, the soil layers are fossiliferous containing numerous land shells, and sometimes carbonized plant fragments. The dune rock itself contains occasional Helicid land shells. The discovery of alleged human impressions in the dune sandstone has occasioned much discussion (Officer, 1892; McDowell, 1899; Pritchard, 1895; Gregory, 1904; MacDonald, 1904; Chapman, 1914) but they are generally regarded as very doubtful. Footprints of birds and animals have been found (Chapman, 1914).

2. Origin.

Present conditions are not adequate to account for the Warrnambool dunes because:

1. Although of aeolian origin, the dunes descend to a considerable distance and depth beneath the sea, in spite of a Recent uplift of about 15 feet above sea level (p. 143).

2. The presence of soil layers and of unconformities in the dune rock indicates some alternation of conditions.

3. The present quantity of shells and other calcareous tests available for fragmentation into sand cannot account for the accumulation of so immense an amount of dune-rock.

4. The dune-rock cliffs are at present being rapidly broken down by wave action, i.e., the existing forces of denudation markedly exceed those of construction.

5. Offshore there is a submarine valley, partly at least in the dune rock.

As the wind-bedded rock extends below the present sea level, the dunes must have been built when the sea was relatively much lower than it is now. In recent times the sea has been about 15 feet higher than now (p. 143), but in Pleistocene times there was a big eustatic drop in sea level. Hills (1939) has drawn attention to the work of Sayles (1931) on the ancient dunes of Bermuda, and suggested an analogy between them and Australian formations. Sayles states that the soil horizons in Bermuda represent the less adverse conditions of the interglacial periods. Daly (1935) states that the last eustatic drop in sea level was of the order of 75 metres which would join Tasmania and Victoria, and this fits in very well with the essential identity of the faunas and floras on both sides of Bass Strait. An Ice Age origin for the dunes also explains the third point set out above, concerning the quantity of material involved in the construction of the dunes. Of this Daly (1935, p. 197) writes, "When, with each major

glaciation, the strand-line moved outward over the gently sloping shelves surrounding continents and islands, wide areas of loose marine sands and muds were exposed to the winds. The dried sands were lifted and carried inland by the onshore winds." Furthermore, since the deposition of the dune sandstone, marine and estuarine shell beds have been laid down (probably by post-glacial high-level seas) along the lower reaches of the Hopkins River, in Lake Pertobe, at Dennington, at a locality near Tower Hill, and at Port Fairy. Also since the deposition of these shell beds the Tower Hill volcano has been active and then become extinct. The consolidated dune sandstone is therefore older than Holocene and is to be referred to the Pleistocene period. If the soil horizons represent interglacials, then the formation covers most, if not all, of the Pleistocene period.

Mr. W. J. Parr has kindly examined material collected from the beach on the west side of the mouth of the River Hopkins, and from the Pleistocene dune sandstone at Steer's Quarry, Warrnambool. From the former locality he has determined *Discorbis dimidiatus* (Jones and Parker), *D. australis* Parr, *Elphidium macellum* (Fichtel and Moll), *E.* sp. indet., and *Quinqueloculina lamarckiana* d'Orbigny. From the latter locality the same species of *Discorbis* and *Elphidium* were found, in addition to *Quinqueloculina* sp. indet., and *Triloculina trigonula* (Lamarck). Mr. Parr has noted that the species of foraminifera are all common in Victorian shore sands, but that in the above samples they were commoner in the Hopkins beach sand than in the Warrnambool dune rock.

In discussing the dunes of the adjacent Portland District (which has a similar structure to that of Warrnambool), Coulson (1940) claims that "The widespread formations at 400 to 500 feet altitude, which cover the basaltic Portland promontory and its westward extension to Swan Lake and Mt. Kincaid, indicate uplift of the order of 400 feet, after allowing 100 feet as the height to which dune formations can be built and levelled off in this district." Thus Coulson holds that ordinary dune-building forces in this part of Victoria could not have elevated the sand above 100 feet. However, it should be noted that—

1. Similar sea-line dunes occur at Warrnambool (60 miles from Portland) to over 160 feet, and these may be compared with those on King Island to 250 feet (Debenham, 1910), at Sorrento to 225 feet (Gregory, 1901), at Anderson's Inlet to 250 feet, in the Glenelg area to 300 feet, and in West Australia to 300 feet (Etheridge, 1876).

2. Coulson postulates uplift to explain dunes at 400-500 feet, yet explains dunes from 500-740 feet as due to migration up slopes. May not the dunes at 400-500 feet be due to similar migration?

3. The factors limiting the height of such dunes (as described, e.g., by Cornish, 1896-7, and Olsson-Seffer, 1907) apply only to sands in open country, and not to sands migrating up slopes. Worcester (1939, p. 229) refers to the piling up of dune sands to over 1,000 feet in the San Luis Valley, Colorado.

The present writer is of the opinion that there has been no post-Pliocene uplift of the order of 400 feet in the Portland-Warrnambool area.

## The Holocene Shell Beds.

In 1917 Chapman and Gabriel listed shells collected from a small patch of rock about 100 yards upstream from Flett's boatsheds on the west bank of the River Hopkins. Deposits extending for about a mile have now been traced on the east bank of the river, overlain by tuff (Pl. II., fig. 8). In the section shown in the photograph there are the following thicknesses of deposits:—

9 inches soil.

3 ft. 3 in. tuff.

3 inches to 1 foot agglomerate composed of sand and angular fragments of dune rock.

14 ft. 6 in. limestone composed of numerous Holocene shells in cemented calcareous sand.

The rock is often crowded with shells, many of the bivalves having the two shells still together, showing that they were deposited in quiet waters and not thrown up on to a storm beach by waves. The shells are generally whole. The highest placed fossil observed was collected from 11½ feet above high-water mark (the river is tidal as far up as Allansford). Flat smooth pebbles of dune sandstone are common in this Holocene deposit, a layer of 9-inch thick being developed in one locality. Chapman and Gabriel thought that the Hopkins shell-rock was part of the Pleistocene dune formation (pp. 4, 13). However, the examination of further outcrops on the opposite bank of the river shows that the deposit is resting on dune rock, and is largely composed of materials derived from the dunes, and therefore is to be regarded as post-dune. The fossils are all of recent character. The same authors attributed the height of the shell bed to "local uplifts due to volcanic activity in the western district" (p. 5). An explanation based on the world-wide drop in sea level in recent times advocated by Daly (1935), is also feasible.

Similar Holocene shell beds occur on the flats at the northern end of which is Lake Pertobe, where boring has proved a thickness of 20 feet of sediments over the dune-rock. Chapman and Gabriel (1917) also reported on shells collected from this locality but considered that "this deposit probably belongs to a

later episode than the shell-beds underlying the tuffs." The Merri Canal has exposed these beds, some of which are still loose and some consolidated. The beds are packed with shells, most of which are whole, and many of the bivalves have the two shells still in place. At the upstream end of the flats, near the Warrnambool Woollen Mill, oyster shells are common. On the Merri Canal 4½ inches to 5 feet of these Holocene shell beds are exposed above river level on the west bank.

Shell beds are also known at Dennington (Chapman and Gabriel, 1917, p. 4), where a fauna was obtained 8 feet from the surface, and underneath volcanic tuff. Records of bores show that underneath this shell bed there is a boulder bed of at least 15 feet thickness. Behind the ocean foredunes there is a swampy area which leads right up to Dennington (fig. 4). In very rough weather the sea washes over into this swamp. On the road from Warrnambool to Dennington about 200 yards east from the turn off to Cassidy's Bridge, an excavation for a large electric power line pole brought up numerous flat pebbles and sea shells, some of the latter being water-worn.

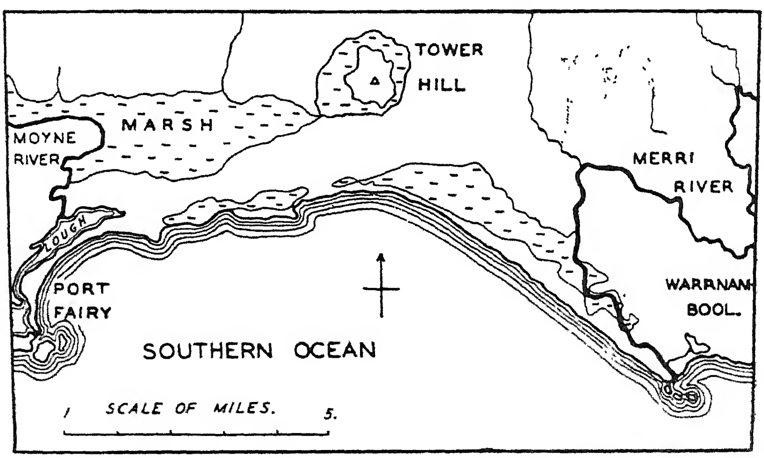


FIG. 4.—Map (after Archibald, 1891) showing stream-pattern in Warrnambool District.

The shell beds at Dennington, Lake Pertobe, and Hopkins River, rising to a maximum height of 14½ feet above sea level, indicate a relative uplift of the land of at least that amount. This is referred to in the present paper as the 15 feet uplift.

Shell beds not unlike those at Warrnambool are known also at Port Fairy (Rawlinson, 1878, p. 31), Gellibrand (Murray, 1877, p. 127), and in the Port Philip area (Hills, 1939, p. 90). Coulson (1940) has brought forward evidence of a 10-ft. relative rise

of the land in the Portland district. David (1914) remarks, "The so-called raised beach of about 15 feet is so general around Australia, that it is probably due to a eustatic negative movement of the sea surface" (p. 289).

That the relative fall in sea level at Warrnambool was a recent one is corroborated by some physiographic features. On the north boundary of Lake Pertobe is the precipitous scarp of Cannon Hill (Pl. II., fig. 6). This is an old sea cliff, while the gentler slope in the foreground is due to the piling of volcanic tuff against this cliff. When a trench for a water main was dug at the railway crossing just west of the Warrnambool railway station, a sea shell (*Trochus undulatus*) was found in dune rock under tuff This shell was complete and is the only sea shell which has been found in the dune rock. It is significant that it is at the foot of this cliff. The scarp passes in one direction round to the Woollen Mill, and in the other past the lighthouse towards the Hopkins River.

## The Holocene Tuff.

Nine miles west of Warrnambool is the extinct volcano of Tower Hill, which was of the explosive type, and tuff and fine lapilli ejected from it extend eastwards a little beyond Warrnambool. Apart from accumulations in depressions such as the valley of the Merri River, the capping of tuff does not exceed 3 feet in the vicinity of Warrnambool. Greater thicknesses are found to the north-east of the volcano, showing that the prevailing winds during the eruption were south-west as they were in the Pleistocene (deduced from the orientation of the dunes), and are now. Errey (1894, p. 24) thought that the tuff had been laid down under water. There is no evidence for this apart from the tuff in the river beds. Similar stratification of the tuff (Pl. II., fig. 7) is seen on the top of the cliffs at Thunder Point, on the sides of the hills, and in the hollows. Tuff is prominent all along the banks of the River Merri, so much so that locally the rock is known as "Merri stone". It is also an important constituent of the river flats where sometimes it is bedded and sometimes mixed with alluvium. An interesting structure observed in the banks of the Merri River (Pl. II., fig. 1) is a sub-circular arrangement of the "stratification". The weathering of the variant textures in the tuff shows that apparently the volcanic dust mixed with the water of the river until a viscous consistency was attained, whereupon it was turned over so as to appear somewhat like a stiff cake mixture which has just been stirred.

In addition to the tuff shown on the maps, there are many little patches too small to be so recorded. Former small hollows in the terrain have been filled up and levelled off with deposits of tuff. Also some soils show by their colour and texture that they have been admixed with tuff. An interesting profile is to be seen in a quarry between Nicholson-street and the railway line (Pl. II., fig. 9). From the bottom up the layers are:—

Consolidated dune limestone.

18 inches black " fossil " soil horizon.

6 inches buff coloured calcareous sand.

6 inches tuffaceous sand layer.

2 inches present black soil layer with grass.

The Merri River runs for a considerable distance on a bed of tuff, which can be seen outcropping on its banks to a depth of 10 or 15 feet, and in places there are small islands of tuff. For some distance upstream from the Wollaston bridge, the tuff is piled high against the eastern side of the valley.

The tuff is fossiliferous in places. Carroll (1898) found the skeleton of a dingo at Tower Hill 60 feet from the surface. Walcott (1920, p. 69) refers to " large and deep footprints, measuring about 9 inches in length, in volcanic tuff, which were exposed in the floor of a cutting made to connect Nestle's Milk Factory with the railway line at Dennington, near Warrnambool ". Chapman (1926) records a leaf, *Eucalyptus* sp., from the tuff.

The stratification of the tuff (Pl. II., fig. 1) as seen at Warrnambool and to even more marked degree at Tower Hill itself, shows that the volcanic activity was intermittent. Bonwick (1858, p. 61) records a layer of black soil and remains of vegetation at a depth of 120 feet interbedded with tuff. On the west bank of the Merri River, ¼ mile upstream from the Wollaston bridge, the following section can be seen (the lowest outcropping stratum being named first:—

15 inches dark-grey ash with fine lapilli.

5 inches light-grey ash, graded thick to fine upwards.

2 inches clay.

3 inches ash with fine lapilli.

8 inches laminated clay in layers of about ½ inch.

6 inches dark ash with fine lapilli.

9 inches clay and ash mixed, merging upwards into light-grey ash.

The alternation of beds of fine clay with beds of tuff indicates a discontinuity at least at this point in the deposition of the volcanic material. However, such alternation of bedding is rare.

The volcanic ejectamenta are of very recent age because—

1. They rest on the Holocene shell-beds described above (Pl. II., fig. 8). This means that the tuff is later than at least the beginning of the post-glacial recession of the sea (if the 15-foot relative rise of the land at Warrnambool is due to this cause).

2. At Cannon Hill, Warrnambool, the tuff rests against the base of an old sea cliff which is only a few feet above sea level. The town clerk of Warrnambool (Mr. H. J. Worland) has a photograph showing high seas washing over the foredunes into the lake at the bottom of this cliff. The preservation of this bank of tuff without apparent erosion, and of a similar bank a little further east near the lighthouse (fig. 1) is evidence that the tuff has been deposited since the completion of the post-glacial recession of the sea.

3. Where tuff rests on hillsides in the areas mapped, it has been noted that it always follows the present contours of the countryside.

4. The Merri River has not yet cut through the tuff in its bed.

5. Mulder (1909) claims that the meaning of aboriginal names "shows that they saw the volcanoes in action, but at a period so remote that even tradition had died out, the names only surviving."

However, Mr. A. S. Kenyon (personal communication) informs me that the meanings given by Mulder are incorrect, and are to be ascribed to "wishful thinking and blackfellows' courteous replies".

## The Holocene Alluvium.

Along the Merri River from Cassidy's Bridge upstream, there are river flats situated generally about 15 feet above river level. Tuff outcrops along the banks of the river for most of the way, and it is commonly met with in excavations on the flats. The alluvium is itself sometimes seen clearly to contain tuffaceous material. The deposition of tuff in the valley is considerable as so much was washed off the sides of the valley into the river course. The result was a building up of the river bed by more than 15 feet, thus slightly rejuvenating the stream which has cut

through this new bed to an average depth of 15 feet. Below Cassidy's Bridge are many swamps and flats covered with reeds. These are covered in flood-time, whereas the high level alluvium just referred to is not now reached by flood waters. Many of these low-level flats are in the nature of dune swales which have been extended by fluviatile and marine action.

Russell's Creek, a tributary of the Merri River, has two levels of alluvium in the upper and lower parts of its course respectively, and these will be described in the physiography section.

The map of Warrnambool constituting fig. 1 shows a patch of alluvium in the vicinity of Japan-street. This is a swale hollow which used to become a lake in winter until a tunnel 27 chains long was cut through a dune ridge to the sea.

Lake Pertobe is bounded on the east, west, and south by alluvial deposits which have been superimposed on the Holocene marine shell-beds already described. In the winter the lake extends considerably, and the alluvium is thus partly lacustrine and partly due to wash from the higher ground surrounding the flats. The alluvium near the lake abounds with the shells of small freshwater mollusca. Alluvium with similar shells occurs on the south bank of the Merri River near the outcrop of Miocene limestone 2½ miles upstream from Wollaston Bridge (*vide* fig. 2).

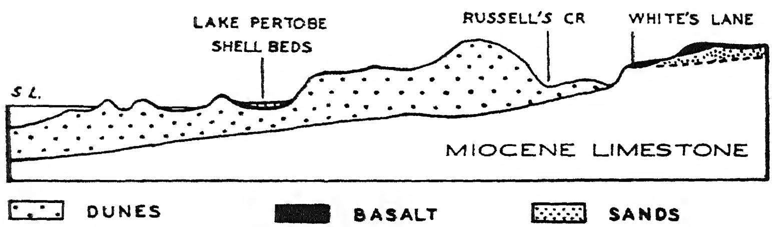


FIG 5.—Geological Section along Liebig-street, Warrnambool, projected to the Wangoom Road in the north, and to a short distance seawards from Pickering Point in the south.

## The Holocene Dunes.

Fringing the ocean for the whole area mapped (fig. 1) there are mobile dunes which are Holocene in age, although composed of the same calcareous sand as the Pleistocene consolidated dunes. For most of the distance they cap the consolidated dune cliffs, but east of Lake Pertobe they occur at sea level. Originally these dunes were closely covered with ti-tree (Osburne, 1887) as is indicated by the presence of numerous root incrustations (cf. Hall, 1901).

The former Government botanist, Baron von Mueller, introduced marram grass as a means of re-anchoring the sand of the mobile dunes, and where developed this treatment has proved successful (cf. Matthews, 1934, p. 90). However, as the grass grows higher so the dunes mount, with the result that they are now much higher than formerly. For instance, the dunes at the Warrnambool Beach (east of Lake Pertobe) used to be so low that during the winter storms the sea water would drive over them and run into Lake Pertobe towards Cannon Hill, but now they have built up to about 20 feet high.

At the mouth of the Hopkins River (west side), at Thunder Point, and at a few other points, the mobile dunes can be seen to be resting on a bed of tuff from 2 to 3 feet thick.

## Palaeogeography and Physiography.

North of the city of Warrnambool there runs a clearly defined scarp from 15 to 20 feet high, which is probably the Pliocene shoreline. This scarp consists chiefly of basalt, which is to be expected since it is so resistant a rock, but it is not simply due to differential erosion because the basalt occurs in some places at a lower level in front of this scarp, e.g., at the north-east corner of the Warrnambool racecourse and at White's-lane. The Pleistocene dunes were piled against this barrier, and the Merri River has 3½ miles of its course marginal to it. From the scarp the underlying Miocene limestone shelves away southwards towards the sea, as the following figures indicate:—

At White's-lane, about 70 feet above sea level.

Albert Park, about 26 ft. 6 in. above sea level.

Spence-street, about 20 feet below sea level.

Lava-street, about 10 feet below sea level.

Sanitary Depot, about 67 feet below sea level.

On this slope, which would be left dry by the retreating Pleistocene sea, the sand dunes were built up, and in time consolidated by the secondary deposition from percolating waters of calcium carbonate. The advancing sea began the demolition of these dunes, the sea being then some 15 feet higher than it is now. Parts of the post-Pleistocene shore line can still be seen as described in the section on the Holocene shell beds. Borings have shown that the dune rock floor below the Lake Pertobe shell beds slopes from the foot of Cannon Hill to a depth of 26 feet below ground level when the beach is reached.

Lady Bay (or Warrnambool Bay as it is called on some maps) is an inundated swale, the line of islands and shore platforms on its seaward side being a continuation of the line of dunes which constitute the coastal cliffs. A former course of the Merri River was along the swale behind this first row of dunes. However, sand from the mobile dunes kept blowing into the stream tending to block it and in any case washing into the harbour, so a canal was cut to divert the river. This canal followed the swale behind the second row of dunes. Fig. 1 shows how the alluvium of Lake Pertobe extends up behind the third row of dunes, and Bonwick (1858) suggested that the Merri once flowed out at this point too. The seaward sloping floor beneath Lake Pertobe is consonant with this idea. The present course of the Merri River after leaving the basalt is along the hindermost of the swales which is marginal to the basalt. It is clear too that the Merri River at one time flowed into the sea west of Dennington (fig. 4), and it is probable that it was then that the estuarine beds were deposited there. The Admiralty chart shows a submarine valley south of Tower Hill. The exit to the sea south of Dennington was ultimately blocked by the shifting sand of the mobile dunes, and the impounded waters then found an outlet along the first swale to Lady Bay. A similar thing has happened at Port Fairy to the Moyne River forming the Belfast Lough as it used to be called (Belfast is an earlier name for Port Fairy). *Vide* fig. 4.

The valley of Russell's Creek, a tributary of the Merri River, is characterized by two areas of alluvial flats differing 20 to 30 feet in height, and caused by two bottlenecks in the course. The first constriction is near the mouth of the stream where a line of strongly consolidated dunes is the obstacle. A local base level of erosion has been developed called the "Russell's Creek Flats". The second constriction is in the basalt north of the racecourse.

Bands of hard travertine retard the weathering of the dune rock. Sometimes a whole slope of a hillside can be seen to be determined by the presence of such a band. It is marked along the shoreline where travertine bands form cliff tops which are sometimes undercut by erosion. The erosion of the cliffs is often rapid, due to the washing out of soil layers, which causes the cliff above to collapse. There are wide shore platforms with many solution cups, and in places there are rock stacks and islands rising above the level of the platforms. Caves have also developed in the cliffs. The rapidity of the erosion of the cliffs is indicated by the disappearance of aboriginal kitchen middens which are common along the cliff-tops. In the eleven years the

author has had this part of the coast under observation, one of these middens has completely disappeared. No middens have been found under the volcanic tuff and since this deposit is geologically so recent the length of time of human occupation of the area must be very brief.

The River Hopkins (on the eastern border of the city) is tidal as far as Allansford, where it leaves the basalt. At the mouth there is a bar and a little offshore there is a reef. Mobile dunes cap consolidated dune sandstone on both sides of the mouth, and formerly sand often blew across the mouth blocking the river until the next storm swept it clear. In the interests of fishermen a channel has been blasted through the dune rock bar. North of Flett's boatsheds (west bank) there are high Miocene limestone cliffs, while on the east bank are the Holocene shell-beds. A regular layer of tuff can be seen surmounting the east bank, while on the west bank the tuff occurs only at intervals—generally in hollows. In the lower reaches of the river the stream follows the boundary between the Pleistocene dune rock and the Miocene bedrock. A low island once existed upstream from the bridge (fig. 1), but the erection of a causeway forming the approach to the bridge from the east bank produced new river currents which eroded away the island to a wide mudflat which is bare at low tide and covered by about a foot of water at high tide. South of Lady Bay there is only one submarine valley, which suggests that the Hopkins and Merri Rivers may have entered the sea by a common stream when the sea level was lower than it is now.

In the map (fig. 4) it is seen that the direction of flow of streams is dominantly in two directions—the one, north to south, and the other, west-north-west to east-south-east. Although the streams flow on Miocene limestone, Pliocene basalt and sub-basaltic fluviatile deposits, Pleistocene dune limestone, and Holocene tuff, they all conform to this same stream pattern. The reason is that the physiography is dominated by the basalt, because where streams flow on the Miocene limestone or sub-basaltic deposits they are superimposed, where they flow on dune rock, the dunes are aligned to the basalt, and where they flow on tuff, they flow in courses previously determined.

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## Description of Plate.

PLATE II.

FIG. 1.—Subcircular "stratification" in tuff on bank of Merri River south of Woodford. *Vide* text p. 145.

FIG. 2.—The lowest and largest soil horizon seen in the cliffs at Thunder Point.

FIG. 3.—Cliff near Thunder Point showing three soil horizons close together and a fourth under the tuff at the top of the cliff. The horizons are numbered on the photograph 1-4.

FIG. 4.—Shore platforms in dune rock near Breakwater Rock.

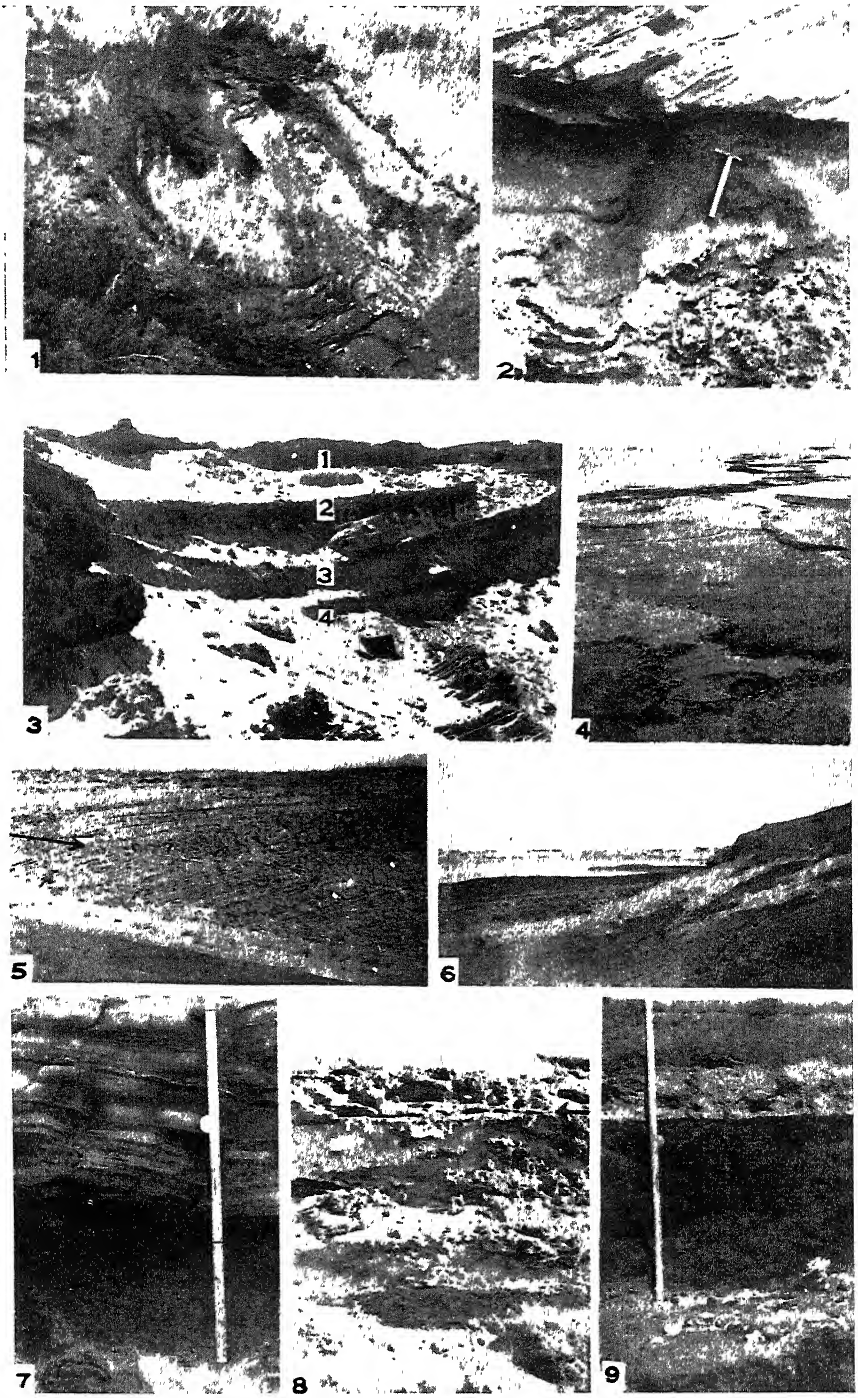
FIG. 5.—Road section, Nicholson-street, Warrnambool. On the planated surface of an older dune, a newer one has been constructed. The arrow on the left of the photograph indicates the break between the two formations.

FIG. 6.—Cannon Hill, Warrnambool, with Lake Pertobe in the background. In the foreground, the slope is composed of tuff piled up against the old sea cliff, which is represented by the precipitous rocks seen beyond the slope.

FIG. 7.—Banded tuff on soil layer, which in turn rests on consolidated dune rock at Thunder Point, Warrnambool. The lower end of the ruler is resting on the dune rock.

FIG. 8.—Holocene shell beds on the Hopkins River, surmounted by a layer of tuff. The arrow on the right of the photograph indicates the upper limit of the shell beds and the beginning of the tuff.

FIG. 9.—Profile in quarry near Nicholson-street. For details *vide* text, p. 146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[PROC. ROY. SOC. VICTORIA, 55 (N.S.), PT. II., 1943.]

# ART. VII.—*The Genus Lepidocyclina in Victoria.*

By IRENE CRESPIN.

(Commonwealth Palaeontologist.)

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## Abstract.

The systematic study of the genus *Lepidocyclina* in the Victorian Tertiary sediments, shows that it is represented by the subgenus *Trybliolepidina* which is characteristic of the upper Middle Miocene and Upper Miocene in the Indo-Pacific region. Three species occur, viz., *L.* (*T.*) *batesfordensis* sp. nov., *L.* (*T.*) *howchini* Chapman and Crespin and *L.* (*T.*) *gippslandica* sp. nov. The *Lepidocyclina* horizon in Victoria is placed near the boundary between the Burdigalian and Vindobonian stages in Europe.

INTRODUCTION.

PREVIOUS LITERATURE ON THE GENUS IN VICTORIA.

REMARKS ON PREVIOUSLY RECORDED SPECIES.

SYSTEMATIC STUDY OF THE GENUS.

DESCRIPTION OF SPECIES.

THE STRATIGRAPHIC POSITION OF THE Lepidocyclina HORIZON IN VICTORIA.

THE AGE OF THE Lepidocyclina HORIZON.

ACKNOWLEDGMENTS.

BIBLIOGRAPHY.

EXPLANATION OF PLATES.

## Introduction.

The genus *Lepidocyclina* was instituted by Gümbel in 1870, and belongs to the group of orbitoidal foraminifera which is of considerable importance in the zoning of the Tertiaries in all parts of the world. It is abundantly represented in the Miocene in the Indopacific region, which includes Australia. The species of *Lepidocyclina* found in the Miocene deposits of Western Australia are referable to those recorded from the Netherlands East Indies, Papua and New Guinea, but the Victorian forms suggest the presence of an embayment in South-Eastern Australia in which other species, but still with Indopacific affinities, flourished. Further support to this theory is given by the molluscan species, which are distinct from those recorded from Western Australia where the affinities are definitely Indopacific. This applies both to Pliocene and Miocene species. Other foraminiferal genera in Victoria with similar tendencies include *Cycloclypeus,* the species

of which show relationship with *C. indopacifica* Tan. and *Austrotrillina howchini* (Schlumberger). This latter form, originally described from Clifton Bank, Muddy Creek, Hamilton, Victoria, has been found in only two other localities in the State, namely, the Mallee Bores and at Skinner's section, Mitchell River, Gippsland. The common Indopacific Middle Miocene genera *Miogypsina* and *Flosculinella* have not been found in Victoria.

*Lepidocyclina* is developed in three separate areas in Victoria. (1) In Western Victoria at Clifton Bank, Hamilton, and in the Hamilton Bore, where numerous tests are present in the samples from 30 feet down to 230 feet. (2) South Central Victoria in the Port Philip Basin, where rich *Lepidocyclina* limestone deposits occur at Batesford, Keilor, and Flinders. The genus is also present in bores in this area. (3) East Gippsland in outcrops and numerous borings. These occurrences will be discussed in Section 6.

## Previous Literature on the Victorian Lepidocyclinae.

The Orbitoids were first recognized in Victoria by the late Professor Howchin, who, in 1889, referred to them as *Orbitoides dispansus*, *O. mantelli* (Morton) and *O. stellata* Howchin from Hamilton.

In 1891, Hall and Pritchard recorded *O. mantelli* from the Batesford quarries near Geelong.

In 1904, Lémoine and Douvillé proved that the forms described by Howchin as *Orbitoides* belonged to the Eocene to Miocene genus *Lepidocyclina*.

In 1910, F. Chapman published his paper on "A Study of the Batesford Limestone," in which he listed three species of Lepidocyclinae—*L. marginata*, *L. martini* and *L. tournoueri*. He also identified a species from Green Gully, Keilor, and from Hamilton as *L. verbeeki*. In 1914 the same author reviewed the various Victorian *Lepidocyclina* localities in his "Homotaxial Relationship of the Australian Cainozoic System."

In 1925, Chapman and Singleton referred to the presence of *Lepidocyclina tournoueri* and *L. martini* in the Middle Miocene bryozoal limestones of Victoria.

In 1926, the writer listed five species of *Lepidocyclina* from vertical sections in a limestone from Green Gully, Keilor—*L. tournoueri*, *L. marginata*, *L. martini*, *L. verbeeki*, and *L.* (*Eulepidina*) *murrayana*.

In 1930, Chapman and Crespin recorded *L.* (*Nephrolepidina*) *borneënsis* and *Cycloclypeus communis* from borings in Victoria. In 1932, they listed five species of *Lepidocyclina* including two

new forms *L. hamiltonensis* and *L. howchini* as well as *Spiroclypeus margaritatus* from the Victorian Tertiaries. Other species recorded were *L. martini*, *L. radiata* and a trigonolepidine form, *L. sumatrensis* forma *mirabilis*. Also in 1932, they zoned the " Lower Miocene " beds in borings in Gippsland on the presence or absence of *Lepidocyclina* and *Cycloclypeus*.

In 1936, the writer listed eleven species of *Lepidocyclina* and one of *Cycloclypeus* from Victoria.

During recent years, palaeontological reports on material from borings in the Tertiary rocks of Victoria have been made by the Geological Branch of the Department of the Interior, Canberra, now the Mineral Resources Survey Branch of the Department of Supply and Shipping, on behalf of the Victorian Mines Department and private companies engaged in the search for oil. These reports contain records of the occurrence of *Lepidocyclina*, which are herein made available for publication for the first time.

## Remarks on Previously Recorded Species.

Prior to the present investigation the following species of *Lepidocyclina* were recorded from the Victorian beds:—

*Lepidocyclina* (*Nephrolepidina*) *angulosa* Provale.
*L.* (*N.*) *borneënsis* Provale.
*L.* (*N.*) *hamiltonensis* Chapman and Crespin.
*L.* (*N.*) *howchini* Chapman and Crespin.
*L. marginata* (Michelotti).
*L.* (*N.*) *martini* Schlumberger.
*L.* (*Eulepidina*) *murrayana* Jones and Chapman.
*L.* (*N.*) *radiata* (Martin).
*L.* (*N.*) *sumatrensis* (Brady).
*L.* (*N.*) *sumatrensis* (Brady) forma *mirabilis*.
*L.* (*N.*) *tournoueri* Lémoine and Douvillé.
*L. verbeeki* Newton and Holland.

In 1939 the writer was privileged to visit the Netherlands East Indies to study with Dr. Tan Sin Hok of the Geological Museum, Bandoeng, Java, the relationship of the *Lepidocyclinae* of that country with those of Australia, Papua and New Guinea. The results of this investigation and further intensive research on hundreds of Victorian specimens are—(1) that the number of species present in Victoria is three, one of which is the already described form *L. howchini*, the other two being new and now designated *Lepidocyclina* (*Trybliolepidina*) *gippslandica* and *L.* (*T.*) *batesfordensis*, and (2) that the records from Victoria of species originally described from outside Australia are incorrect.

The study of the Victorian *Lepidocyclinae* reveals three outstanding characteristics:—

(*a*) All specimens exhibit polygonal features.

(*b*) All megalospheric specimens examined belong to the subgenus *Trybliolepidina* and not to *Nephrolepidina* as previously considered.

(*c*) The median chambers in both megalospheric and microspheric specimens are chiefly ogival to spatulate in shape, hexagonal ones being sometimes present in the rayed portion of the test.

It is these features which exclude from the Victorian assemblage such species as *L.* (*N.*) *tournoueri*, *L.* (*N.*) *bornеënsis* and *L. marginata*. All microspheric specimens have been previously recorded as *L. marginata,* a species in which the median chambers pass from ogival to hexagonal. In the Victorian specimens they are ogival around the protoconch, becoming spatulate to elongate-spatulate towards the margin of the shell. The majority of specimens in horizontal section show a tendency to be strongly rayed for a short distance out from the protoconch.

*L. tournoueri* is nephrolepidine and non-polygonal, with the median chambers typically hexagonal in shape. The species is rare in the Indopacific being probably replaced by *L. bornеënsis* Provale. Chapman recorded *L. tournoueri* as the most abundant species in the bryozoal limestone at the Filter Quarry, Batesford. The dominant form there is gently biconvex, and slightly polygonal in outline; the median chambers are typically ogival to spatulate and the embryonic and nepionic apparatus is trybliolepidine. The species is now referred to as *L.* (*T.*) *batesfordensis.*

*L. borneënsis,* which is apparently the Indopacific representative of *L. tournoueri* is also non-polygonal and nephrolepidine and does not appear in Victoria. Specimens recorded as *L. angulosa* and *L. sumatrensis* are merely fractured tests of *L.* (*T.*) *gippslandica* or *L.* (*T.*) *howchini,* all gradations of fracture being available especially in the Gippsland populations. The specimens listed as *L. murrayana* are abnormal forms of *L.* (*T.*) *gippslandica* or *L.* (*T.*) *batesfordensis. L. sumatrensis* forma *mirabilis* is included here. All specimens previously referred to as *L. radiata* now belong to *L.* (*T.*) *gippslandica.* Martin's description (1880) of the external features of *L. radiata* is applicable to this new species. "Test flat, 8 mm. in diameter, very thin, furnished in the centre with a thick, button-like elevation. From this, nine rays run towards the periphery. These rays are sharply distinguishable from the flat, extended part of the test, lying between them; they are single for their entire extent and end close to the periphery. Between each pair of rays the border of the test is always scalloped once. The surface shows a series of very

fine discontinuous ridges, parallel with the outer edge. Nothing is known of the inner structure. There the rays of the fossil neither bifurcate nor reach the edge. Occurrence of single specimen—Sindangbarang, Preanger, Java." It is unfortunate that the type description is based on the external characters of a single specimen, which is housed in the Leiden Museum, Holland. Nothing is known of the internal structure, but Tan, who has seen the specimen, suspects that it is Trybliolepidine or Cyclolepidine. Until recently *L. radiata* was considered as belonging to "e" stage (Lower Miocene), but it is now known (communication from Tan) that "it must have been derived from the young Tertiary (Young Miocene) Bantang Series of Southern Preanger." Tan had hoped to collect from the type locality but present conditions have prevented this. It is this dearth of information regarding the true characters of *L. radiata* that makes it unsafe to refer to it as a basic species.

The specimens which have been recorded as *L. martini* belong partly to *L.* (*T.*) *gippslandica* and partly to *L.* (*T.*) *howchini*. It is known that *L. martini* is a trybliolepidine but the shape of the median chambers in the rayed portion of the test is hexagonal, whilst in the Victorian specimens, especially in *L.* (*T.*) *gippslandica* and *L.* (*T.*) *howchini*, it is typically elongate spatulate. Schlumberger's description (1900) of the external features of *L. martini* is as follows " Shell star-shaped, thickened at the centre, thinned towards the margin, furnished on the rim with six to eight prominent rays, some sharpened others more or less tongue-shaped. The surface of well preserved individuals has some small granulations at the centre." The type locality is Batoe Koetjing, Madoera. *L.* (*T.*) *howchini* has six to eight blunt rays and usually the surface is rather smooth, although some specimens have a few strong pustules towards the centre of the shell. Specimens referred to as *L. verbeeki* were chiefly from the Hamilton Bore. These are now included under *L.* (*T.*) *batesfordensis*.

## Systematic Study of the Genus.

### Consideration of the Embryonic and Nepionic Apparatus.

#### Megalospheric Generation.

The division of the Lepidocyclinae into subgenera was originally based on the arrangement of the embryonic (initial) chambers, but in recent years the study of the nepionic (auxiliary) chambers is considered of equal importance.

In 1904 Lémoine and R. Douvillé recognized two different types of embryonic apparatus and also distinguished between the microspheric and megalospheric forms. H. Douvillé, in 1911, instituted the terms *Nephrolepidina* and *Eulepidina* for these two types. In 1924, he added two more subgenera, namely *Isolepidina*

and *Amphilepidina*, the former being based on the structure of the embryonic apparatus and the latter, not only on the shape of this apparatus but also on that of the median chambers. In 1928, Van der Vlerk created the new subgenus *Trybliolepidina,* Galloway in 1933 designating as its type species Van der Vlerk's *L. rutteni*, described in 1924 from Tji Boerial, Preanger, Java. Van der Vlerk considered this subgenus an important index group indicating the top of stage " f " or Upper Miocene. Gerth, in 1930, stated that " As species of *Lepidocyclina* which show a transition from the *Nephrolepidina*-stage to the *Trybliolepidina*-stage have already been found in the older Miocene, the occurrence of *Trybliolepidina* is not a true indication for the younger Miocene. But if *Trybliolepidina* is only found without true *Nephrolepidina*, it is very probable that beds of the younger Miocene have to be dealt with." He considered the " older Miocene " as Burdigalian, the " younger Miocene " as Vindobonian. In the same year Tan pointed out that not the subgenus *Trybliolepidina* but some of its species are stratigraphically important. Vaughan and Storrs Cole (in Cushman 1940) considered that the subgenus should not be recognized their reasons being based on Caudri's work in 1939.

Recent investigations on material from bore section and outcrops in North-west Australia, Papua and New Guinea indicate that this subgenus is of definite stratigraphic value. The stratigraphically highest *Lepidocyclina* to be met with in these areas always belongs to the subgenus *Trybliolepidina.*

The outstanding feature of the study of crowds of Victorian specimens is the persistence of the type of nepionic apparatus, which has one or two nepionic chambers fewer than *L.* (*T.*) *rutteni*, the species upon which *Trybliolepidina* is based, and two or three more than in *Nephrolepidina*. The shape of the embryonic apparatus is practically uniform in all sections, the large protoconchal chamber partially embracing the smaller deuteroconchal one.

In discussing the median section of a megalospheric *Lepidocyclina* a certain convenient terminology is used. It was introduced by Henbest (1934) and later developed by Tan (1935).

1. The embryonic or initial apparatus refers to the two most central chambers, the protoconch (P) and the deuteroconch (D). The way in which the deuteroconch embraces the protoconch differs according to the subgenus,

2. The primary stolons are the connecting links between the protoconch and the deuteroconch. They are of two kinds—(*a*) the protoconchal stolons which links the two embryonic chambers, and (*b*) the deuteroconchal stolons which link the deuteroconch with the (nepionic) chambers which immediately surround it.

3. The nepionic chambers are the auxiliary chambers found immediately on the external wall of the embryonic apparatus. They are of two kinds—(*a*) the primary auxiliary chambers (P) which are two in number and overlap the junction between the protoconchal and deuteroconchal chambers, and (*b*) the adauxiliary chambers (Ad) which are attached to the external wall of the deuteroconch, being developed from the deuteroconchal stolons. They vary in number according to the subgenus. Six are the characteristic number in the Victorian specimens. They are absent in the subgenus *Eulepidina.*

4. The nepionic stolons are two in number and are produced from the nepionic chambers on either side of the frontal wall. They are called posterior and anterior. They are frequently difficult to see in sections.

5. The neanic stage is the series of budding immediately surrounding the nepionic chambers, being an intermediate stage between the embryonic apparatus and the cyclic chambers which continue until the shell has completed growth.

The structure of the embryonic and the nepionic apparatus in the Victorian Lepidocyclinae is illustrated in Fig. 1. Fig. 1A represents a median section through a megalospheric specimen of *L.* (*T.*) *batesfordensis* from the old Filter Quarry, Batesford. Fig. 1B is of a specimen of *L.* (*T.*) *gippslandica* from No. 5 Bore, Parish of Glencoe, Gippsland. Both sections were cut and the structural features indicated under the supervision of Dr. Tan Sin Hok.

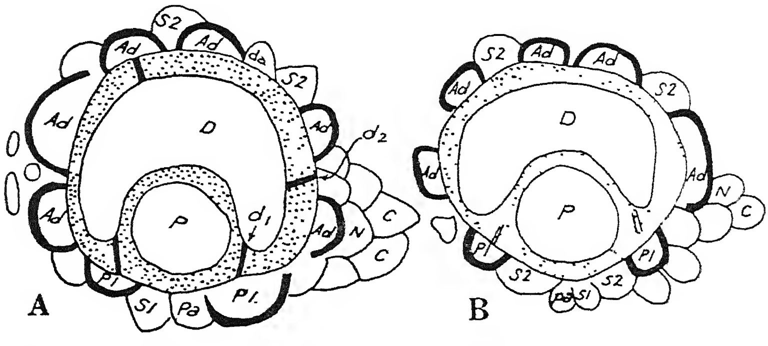


FIG. 1.—P, protoconch; D, deuteroconch; Pl, primary auxiliary chambers; Ad, adauxiliary chambers; S1, S2, symmetric nepionic chambers; pa, asymmetric nepionic chambers; da, asymmetric deuteroconchal chambers; N, neanic stage, C, cyclic chambers; d1, primary stolons; d2, stolons linking deuteroconch with adauxiliary chamber.

It will be noticed that the embryonic apparatus consists of two chambers—the protoconch (P) which is partly embraced by a larger chamber, the deuteroconch (D). The outer wall of the

embryonic apparatus is thick, a persistent feature of the tryblio-lepidine type. Four deuteroconchal stolons are seen in the Batesford specimen but none is visible in the Glencoe form. Two primary stolons ($d_1$) link the deuteroconch with the primary auxiliary chambers just at the point where the deuteroconchal wall meets the protoconch. Two other deuteroconchal stolons ($d_2$) are visible passing through the deuteroconchal wall into adauxiliary chambers. Surrounding the external wall of the embryonic apparatus in the Batesford species are eight nepionic chambers, which represent budding periods. Two primary auxiliary chambers (pa) overlap the point where the protoconchal and deuteroconchal walls meet, while six adauxiliary chambers (Ad.) bud off from the external wall of the deuteroconch. This number is fairly uniform in the Victorian specimens. In the Batesford population there are variations from 5 to 8 with 4 very rare. In *L.* (*T.*) *ruttem,* they vary from 6 to 11. In *L.* (*T.*) *gippslandica* adauxiliary chambers are present with 4 to 6 being the most constant. Three specimens showed 3, which suggests Nephrolepidine ancestry.

In all sectioned specimens, the chambers constituting the juvenarium are ogival in shape.

MICROSPHERIC GENERATION.

The structure of the embryonic apparatus of all microspheric forms of *Lepidocyclina*, whether nephrolepidine or trybliolepidine, is fairly constant. In the Victorian specimens, there is a large initial chamber which is surrounded by six smaller initial ones arranged in a single spiral. The polygonal arrangement of the median chambers is not apparent until four spirals of larger chambers have been developed. The plani-spiral arrangement of the microspheric nucleoconch is constant in all genera of the Orbitoididae, the specific determinations being made on the shape of the median chambers.

Workers on the Lepidocyclinae in Europe and the Netherlands East Indies have, for the most part, given definite specific names to microspheric forms without regard to the megalospheric species to which they may be related. This method of nomenclature is incorrect when the microspheric generation occurs with a population of megalospheric specimens all of which can be referred to the one species. Such is the case in the Upper Quarry at Batesford, where parts of the limestone are made up almost entirely of tests of megalospheric and microspheric examples of a single species of *Lepidocyclina,* and similarly in the Gippsland bores. As a result, in this work, the microspheric form is referred to as " Form B " of the species with which it is closely associated.

## Description of Species.

LEPIDOCYCLINA (TRYBLIOLEPIDINA) GIPPSLANDICA sp. nov.

(Plate III., figs. 1-7; Plate VI., figs. 22-28.)

FORM A.

*Lepidocyclina (Nephrolepidina) radiata* Chapman and Crespin (non Martin), 1932, p. 95, pl. xiii., figs. 15-17.

*Lepidocyclina (Nephrolepidina) martini* Chapman and Crespin pars (non Schlumberger), 1932, pl. xii., figs. 11-14. Crespin, 1936, p. 10, pl. ii., figs. 25, 26.

External characters of holotype.—Test with polygonal outline. Surface smooth except for 9 pustules on central boss. Nine rays extend from central portion towards periphery, where they flatten out and do not protrude beyond edge. Median chambers seen towards edge of shell. Diameter of test—5 mm.; thickness at central boss—2 mm.

Internal characters of tectotype.—(*a*) Median Section. On account of the wavy nature of the test, it is difficult to obtain perfect sections. Median chambers thin walled, arranged in polygons, with narrow rays which commence a short distance out from the embryonic apparatus, and broaden out towards margin. Chambers in rays chiefly elongate spatulate, rarely hexagonal. Chambers immediately surrounding nepionic apparatus ogival and between rays pass from ogival to spatulate towards periphery. Embryonic apparatus trybliolepidine, with 7 nepionic chambers. Outer wall of protoconchal and deuteroconchal chambers thick. Width of protoconchal chamber 0·16 mm., deuteroconchal 0·33 mm.

(*b*) Vertical section. Test biconvex. Lateral chambers rounded, showing curved horizontal walls; thin walled, 9 layers; strong pillars in central portion.

Locality of holotype and tectotypes.—No. 5 Bore, P. of Glencoe at 70 feet (Com. Pal. Coll. Nos. 39 and 212).

Paratypes.—(*a*) No. 15 Bore, P. of Stradbroke at 45 feet. External characters similar to holotype. Polygonal outline pronounced, 9 rays showing thickening and broadening towards periphery. Surface slightly pustulate, due to weathering of specimen. Central pustules strong. Diameter—5 mm.; thickness at central boss—2 mm.

(*b*) Locality as (*a*). Test rayed, with 10 flattened rays protruding beyond edge of shell, due to fracturing of test between rays. Surface rough, central boss pustulate. Diameter—4 mm.; thickness at centre 1·5 mm .

(*c*) Skinner's Section, Mitchell River, P. of Wuk Wuk. Test fractured but 8 flattened rays visible. Surface slightly roughened with weathering. Pustules on central boss. Diameter—5 mm.; thickness 2 mm.

Observations.—As previously stated, perfect specimens of *L.* (*T.*) *gippslandica* exhibit the external features of *L. radiata* Martin, as well as intergradations between Scheffen's form *L.* (*T.*) *rutteni* forma *globosa* and *L. martini* Schlumberger. In horizontal section the persistent shape of the median chambers which range from ogival to spatulate, with occasional tendency to hexagonal in the rayed portion prevents the species being classed with *L. martini.* In vertical section the species is closely comparable with *L.* (*T.*) *rutteni* forma *globosa* not only in the general outline but in shape of the lateral chambers which are rounded rather than rectangular. In the horizontal direction, the similarity is in the structure of the embryonic apparatus, which shows 4 adauxiliary chambers. In *L.* (*T.*) *gippslandica* the number varies from 4 to 5. Two specimens had 6 and two had 3. The main difference is that in *L.* (*T.*) *rutteni* forma *globosa,* the rays are 5 in number, and strongly developed, the chambers in that region being typically hexagonal.

*L.* (*T.*) *gippslandica* is the predominant species in the Gippsland borings and outcrops. The majority of specimens are small averaging about 3·5 mm. in diameter. This slight variation from the size of the type is due to the fracturing of the margin of the test to a distance fairly close to the central portion. In populations such as are found in No. 5 Bore, P. of Glencoe, at 70 feet, in No. 15, P. of Stradbroke at 45 feet, and in Brock's Quarry, the gradual gradation from perfect specimens as exhibited in the type specimen, to those smaller fractured ones, such as predominate the populations, can be well studied, and it is only by such study that the existence of only one species can be demonstrated.

The species is recorded from the base of the New Quarry at Batesford (collected by F. A. Cudmore) where it is associated with *L.* (*T.*) *batesfordensis,* the main development of the latter species being in the upper beds of the section. In the Gippsland bores *L.* (*T.*) *gippslandica* is always most abundant in the zone where it is associated with *Cycloclypeus victoriensis* var. *gippslandica* Crespin which underlies that in which *L.* (*T.*) *batesfordensis* is recorded. A similar sequence is found in the Hamilton Bore in Western Victoria, where *L.* (*T.*) *gippslandica* is replaced by the smaller rayed form *L.* (*T.*) *howchini,* which is very common below the lowest depth at which *L.* (*T.*) *batesfordensis* is present.

*L.* (*T.*) *gippslandica* is associated with *Austrotrillina howchini* (Schl.) at Skinner's, as well as with *Hofkerina semiornata* (Howchin), *Planorbulinella inaequilateralis* (Heron-Allen and Earland), *P. plana* (H-A. and E.) and *Gypsina howchini* Chapman, which are always present.

Occurrence.—The localities for the holotype and paratypes have already been listed. Further localities include 56 bores in Gippsland. The shallowest depths from which the species have been recorded are at 45 feet in No. 15 Bore, P. of Stradbroke, and at 50 feet in No. 5 Bore, P. of Glencoe, and the greatest depth in the Holland's Landing Bore, P. of Bengworden South, where it was found at 1,886 feet. Cliff and quarry sections in Gippsland include Skinner's, Mitchell River, P. of Wuk Wuk; E. of Hillside Bridge, North Cliff, Mitchell River, P. of Moormurng; Boggy Creek at Bridge near junction with Mitchell River, P. of Wy Yung (collected by officers of Victorian Mines Department); Brock's and Le Grand's quarries, P. of Glencoe (coll. I.C.). Other localities include New Quarry, Batesford near base of section (coll. F.A.C.).

FORM B.

Paratype.—From No. 15 Bore, P. of Stradbroke, Gippsland, at 45 feet. External characters—Specimen with fractured edge, biconvex, with numerous pustules in central portion of test. Diameter—7 mm. Greatest thickness 2 mm. (Com. Pal. Coll. No. 198.)

Internal characters (based on a number of thin sections).—Median section—Microspheric nucleoconch, planispiral, showing circular arrangement of chambers in embryonic apparatus, with further initial chambers arranged in spiral. Arrangement of median chambers polygonal, showing 5 rays, in central portion of test. Chambers ogival in rayed portion passing to spatulate and elongate spatulate towards periphery. Test shows considerable regeneration.

Other paratypes.—(*a*) Brock's Quarry, P. of Glencoe. Test discoidal finely pustulose. Diameter 7 mm.; greatest thickness 2 mm.

(*b*) Same locality.—Test thin with indistinct rays present. Strong pustules in centre but surface covered with smooth concentric bands possibly due to weathering.

Observations.—Microspheric specimens are not common and as a result not many sections were available for study, but all showed similar internal features including the central polygonal arrangement of chambers and the ogival to spatulate median chambers.

The tests are not large, the diameter averaging 6 mm. One unusually large specimen with a diameter of 14 mm. was recorded from No. 7 Bore, P. of Glencoe, Gippsland, at 520 feet.

The rayed character of the central portion is a feature of many of the microspheric forms from the Netherlands East Indies, in

which the median chambers are usually elongate-spatulate to elongate-hexagonal. The Victorian specimens are most closely comparable with *L. stratifera* Tan, in which ogival to spatulate chambers are predominant.

Occurrence.—Localities are as listed under the megalospheric form.

LEPIDOCYCLINA (TRYBLIOLEPIDINA) HOWCHINI Chapman and Crespin.

(Plate IV., figs. 8-15; Plate VII., figs. 30-35.)

FORM A.

*Orbitoides stellata* Howchin (*non Orbitulites stellata d'Archiac*, 1850), 1888, p. 17, pl. i., figs. 9-11.

*Lepidocyclina* (*Nephrolepidina*) *howchini* Chapman and Crespin, 1932, p. 94, pl. xiii., figs. 18, 19; Crespin, 1936, p. 8, pl. ii., figs. 17, 18.

*Lepidocyclina* (*Nephrolepidina*) *hamiltonensis* Chapman and Crespin, 1932, p. 93, pl. xii., figs. 8-10; Crespin, 1936, p. 8, pl. ii., fig. 19

*Lepidocyclina* (*Nephrolepidina*) *martini* Chapman and Crespin (non Schlumberger), 1932, pars, p. 95.

*Lepidocyclina* (*Nephrolepidina*) *radiata* Chapman and Crespin (non Martin), 1932, pars, ibid., p. 96.

Holotype of variety.—Description of *L.* (*T.*) *howchini* as given by Chapman and Crespin. "Description of Holotype (from Hamilton Bore, 80-85 feet).—Test small, discoidal with blunt marginal prolongations. Surface strongly convex, central part of test with a group of strong papillae, smaller on surrounding area. Description of Tectotype.—Vertical section from 68-80 feet. Equatorial series narrow, lateral, chamberlets forming 6 layers superimposed on centrosphere, 5 vertical pillars shown in cross section in the central region. Dimensions.—Diameter of test 2·9 mm.; thickness of test, 1·17 mm. Diameter of centrosphere, 0·14 mm.; longest diameter of nucleoconch, 0·41 mm." (Com. Pal. Coll. No. 42.)

Plesiotypes.—(1) Howchin's locality at Clifton Bank, Muddy Creek, Hamilton. External characters—Test small compressed, discoidal, with 8 blunt marginal prolongations, giving stellate appearance. Surface rough, with 9 strong pustules on central portion. Diameter—3·5 mm.; greatest thickness—1 mm.

Internal characters—Median section. Median chambers thin-walled. Rays not pronounced; chambers chiefly ogival in shape, becoming spatulate towards periphery and in rayed portion. Nepionic apparatus trybliolepidine, with 8 nepionic chambers, comprised of 2 primary auxiliary and 6 adauxiliary, embracing the embryonic apparatus. Outer wall of protonchal and deuteroconchal chambers thick. Width of protoconchal chamber 0·20 mm.; of deuteroconchal 0·39 mm.

(2) Specimen from Flinders. Test small, with ten prolongations; biconvex, with strong pustules in centre, diameter—4 mm.

Observations.—A figure of a median section of *L.* (*T.*) *howchini* is not given by Chapman and Crespin but one is shown under "*L. hamiltonensis*." The trybliolepidine nucleoconch is present, with 7 nepionic chambers, including 2 primary auxiliary and 5 adauxiliary. The median chambers in the immediate vicinity of the nepionic apparatus are ogival and pass into spatulate, while the elongate-spatulate shape is recognizable in the rayed portion. Howchin's type specimen of "*O. stellata*" cannot be located either in the Geology Department, University of Adelaide, or in the Howchin Collection in the South Australian Museum. Numerous sections of topotypes have been studied, all showing trybliolepidine affinities. At the same time the study of this population at Howchin's type locality shows that "*L. hamiltonensis*" is synonymous with *L.* (*T.*) *howchini*. Perfect sections of this latter form are difficult to secure on account of the mode of preservation of the tests. All specimens from Muddy Creek and throughout the major part of the Hamilton Bore are iron-stained, those from the lower portion of the bore being partially replaced with glauconite.

*L.* (*T.*) *howchini* is very common at Flinders. It is recorded from the Tyabb Bore, Mornington Peninsula, and at Skinner's section, Mitchell River, Gippsland. It is exceedingly rare in the Gippsland bores. It is usually associated with *Amphistegina* and *Calcarina verriculata* at Hamilton and Flinders.

Tests are invariably small averaging about 3 mm., some of the Flinders specimens reaching 4 mm. The number of blunt prolongations vary from 6 to 8 and rarely 10, while the convexity of the tests is also variable. The surface ornament varies according to preservation, a feature well illustrated in the Flinders specimens which are frequently strongly pustulose.

Occurrence.—Western Victoria. Lower beds, Muddy Creek, Hamilton; throughout the Hamilton Bore down to 187 feet, becoming the predominant species below 80 feet. Port Philip region. Basal beds in New Quarry, Batesford; Water Bore, Avalon, Lara, at 315 feet; Water Bore; Victoria Golf Club, Cheltenham, at 221 feet; No. 1 Bore, Tyabb at 57-90 feet; No. 2 Bore, Tyabb at 173-176 feet; Flinders. Gippsland-Skinner's section, Mitchell River, near Bairnsdale.

Form B.

*Lepidocyclina marginata* Crespin (non *Nummulites marginata* Michelotti), 1936, p. 9, pl. ii., fig. 21.

Plesiotype.—From Hamilton Bore. External characters from specimen at 91-96 feet. Test discoidal, biconvex, with numerous pustules chiefly on central portion. Diameter 5 mm.; greatest thickness 1·5 mm. (Com. Pal. Coll. No. 202.)

Internal characters of specimen at 86-91 feet. Median section—Embryonic chamber indistinct but surrounded by a single spiral embryonic chamber. This in turn is surrounded by chambers arcuate to ogival in shape. These chambers pass outwards into broadly spatulate ones. Hexagonal chambers rare in outer portion due to spatulate chambers not being sectioned through the centre. Polygonal arrangement only faintly suggested, but is stronger in less perfect sections. Vertical section of specimen at 36-38 feet. Structure indistinct because of ironstaining. Central median chambers thin in centre widening out towards margins of shell indicating polygonal character. Fifteen superimposed lateral layers only the outer 8 being continuous throughout the length of the test. The central ones rise convexly from the central median chamber before converging to it. Pillars in outer central portion of test. Lateral chambers slightly convex.

Observations.—Owing to the mode of preservation (all specimens being ironstained) good sections are difficult to obtain. The microspheric specimens from Hamilton are identical with those from Flinders both in external and internal characters. There is little variation in the size of tests. One Hamilton specimen from 86-91 feet had a diameter of 6 mm.; and another from Flinders, 7 mm.

Occurrence.—At various depths in the Hamilton Bore; Flinders; No. 7 Bore, P. of Parwan, at 316-329 feet.

LEPIDOCYCLINA (TRYBLIOLEPIDINA) BATESFORDENSIS sp. nov.
(Plate V., figs. 16-21; Plates VIII. and IX., figs. 36-46.)

FORM A.

*Lepidocyclina tournoueri* Chapman (non Lémoine and Douvillé), 1910, p. 295, pl. liv., figs. 1, 2, 6; Crespin, 1926, p. 114, pl. viii., fig. 7; ibid., 1936, pl. ii., figs. 16, 23.

*Lepidocyclina verbeeki* Crespin (non Newton and Holland), 1926, p. 115, pl. viii., fig. 10.

*Lepidocyclina* (*Nephrolepidina*) cf. *tournoueri* Singleton, 1941, p. 32.

Holotype.—External characters—Test discoidal, fairly evenly biconvex, with peripheral edge sharp and sometimes wavy. Pustules cover test but are stronger towards central portion. Surface smooth near periphery. Diameter 5 mm.; greatest thickness 1 mm.

Internal characters of tectotype.—(*a*) Median section. Median chambers thin-walled, arranged in polygons, with seven broad rays, extending almost to the margin of the test. Chambers immediately surrounding nepionic apparatus ogival in shape, passing from ogival to spatulate towards the edge of the test. Inter-radial chambers chiefly ogival to broadly spatulate. In radial portion they become elongate spatulate with some hexagonal.

Embryonic apparatus trybliolepidine, with 8 nepionic chambers. Outer wall of protoconchal and deuteroconchal chambers thick. Width of protoconchal chamber 0·27 mm.; deuteroconchal 0·5 mm.

(*b*) Vertical section.—Test biconvex, lateral chambers show slightly curved horizontal thin walls with eleven superimposed layers. Strong pillars in central portion.

Locality.—*Lepidocyclina* limestone, Upper Quarry (Australian Portland Cement Co.), Batesford, near Geelong, collected by Dr. F. A. Singleton. (Com. Pal. Coll. No. 206.)

Paratype.—New Quarry, Batesford (collected by F. Cudmore). Test smaller than holotype but with similar characters. Diameter—3·5 mm. Horizontal section shows similar rayed characters, with ogival to spatulate type of chambers. Nepionic chambers 6.

Observations.—Tests of *L.* (*T.*) *batesfordensis* occur in profusion in certain parts of the Batesford quarries. This species is that referred to *L. tournoueri* by Chapman. Specimens from the Filter Quarry were taken to Java by the writer and examined by Dr. Tan Sin Hok. The photograph of one of his sections is shown in Fig. 36. The arrangement of the embryonic apparatus excluded *L. tournoueri* as the possible species and an examination of a great number of sections excluded the possibility of its being present at Batesford. *L.* (*T.*) *batesfordensis* is typically trybliolepidine and polygonal, with chambers ogival to spatulate. As already stated, *L. tournoueri* is nephrolepidine, non-polygonal, with chambers chiefly hexagonal. In all sections examined the character of the embryonic apparatus is uniform, the number of nepionic chambers varying from 6 to 8. The specimens from the upper part of the New Quarry (collected by F. A. Cudmore) are similar in size to those from the old Filter Quarry; but those from the Upper Quarry (collected by Dr. F. A. Singleton and W. J. Parr) were consistently larger. Unfortunately in all cases, perfect horizontal sections were difficult to obtain owing to the wavy character of the test.

At Batesford *L.* (*T.*) *batesfordensis* is associated with *Cycloclypeus victoriensis* together with abundant *Amphistegina lessonii, Calcarina verriculata, Gypsina howchini, Planorbulinella plana* and *P. inaequilateralis.*

The population at Green Gully, Keilor, is dominated by large specimens of *L.* (*T.*) *batesfordensis,* similar to those from the Upper Quarry at Batesford. It is not common at Flinders but tests are fairly numerous in the upper portion of the Hamilton Bore. It is rare in the Gippsland borings being sometimes the first specimen of *Lepidocyclina* to be recorded in bore sections.

Occurrence.—Upper Quarry, Australian Portland Cement Works, Batesford, near Geelong; New Quarry, Batesford; Green

Gully, Keilor; the upper portion of the Hamilton Bore, P. of Yulecart, Western Victoria; Flinders, Mornington Peninsula; and in various borings in Gippsland.

FORM B.

*Orbitoides mantelli* Howchin (non Morton), 1891. In Hall and Pritchard, p. 10.

*Lepidocyclina marginata* Chapman (non *Nummulites marginata* Michelotti), 1910, p. 296, pl. iv., fig. 5; pl. v., figs. 1-3; Crespin, 1926, p. 115; 1936, p. 9.

Paratype.—External characters—Test large, discoidal, thin, biconvex, circular in outline. Numerous small pustules scattered over most of the unweathered test. Surface smooth towards periphery with lateral chambers frequently visible. Periphery rounded. Diameter—11 mm.; greatest thickness 2 mm.

Internal characters from tectotype.—Median section—Microspheric nucleoconch planispiral, showing circular arrangement of chambers in embryonic apparatus, which consists of a central initial chamber surrounded by six similar initial chambers arranged in a spiral. Arrangement of median chambers polygonal, showing 8 rays, as indicated in the megalospheric form. Rays do not extend to edge of test. Chambers surrounding embryonic apparatus and for some distance outwards, ogival in shape, passing into spatulate and elongate spatulate towards periphery. A few hexagonal shaped ones along outer margin.

Vertical section.—Horizontal median chamber thin in centre, widening out considerably towards each end of test. Sixteen superimposed lateral layers, only the outer five being continuous throughout the length of the test. The others rise gently convexly in central portion of test before converging to the central chamber. Lateral chambers thin-walled and straight-sided and do not alternate in their arrangement. A few pillars in centre of section.

Locality.—New Quarry, Batesford, near Geelong, collected by W. D. Chapman. (Com. Pal. Coll. No. 208.)

Another paratype.—Upper Quarry, Batesford (coll. F. A. Singleton). Test discoidal slightly biconvex. Surface free from pustules. Diameter—11 mm.

Observations.—This microspheric form was figured as *L. marginata* by Chapman (1910) who, at the same time, figured a megalospheric specimen. Douvillé (1904) states that only the microspheric form of *L. marginata* was known, but it is quite possible that *L. marginata* represented the microspheric generation of *L. tournoueri*. Chapman's figure (pl. liv., fig. 5) showing the megalospheric nucleoconch is referable to *L. (T.) batesfordensis*, fig. 2, representing the microspheric form of the same species.

The type median section of *L. marginata* shows it to be non-polygonal, while the outstanding feature of *L.* (*T.*) *batesfordensis* form B is its polygonal character.

In the upper quarry at Batesford, the several specimens available are all fractured but some idea of the diameter can be gathered, the variation being from 10 to 17 mm., the majority of specimens averaging 10 mm.

The rayed character of this microspheric form is exhibited in many species in the Netherlands East Indies. The strongly ogival shape of the median chambers in the vicinity of the initial apparatus together with the persistent spatulate shape of the later ones distinguishes the Victorian form from these in which hexagonal shaped chambers are predominant.

Occurrence.—Upper Quarry, Australian Portland Cement Co., Batesford, near Geelong; Green Gully, Keilor.

## The Stratigraphical Position of the Lepidocyclina Horizon in Victoria.

The present investigation indicates that the *Lepidocyclina* horizon in Victoria can be divided into three zones. This zoning is supported by a close study of the Batesford section as represented in the New Quarry, where a systematic collection of material was made by F. A. Cudmore, and of bore sections at Hamilton and in Gippsland. The three zones are—(*a*) an upper one or *zone of L.* (*T.*) *batesfordensis,* which is characteristic of Batesford, where the assemblage is dominated by *Calcarina verriculata;* (*b*) an intermediate one or *zone of L.* (*T.*) *howchini,* typical of Hamilton, where *C. verriculata* is associated with *Hofkerina semiornata;* and (*c*) a lower one or *zone of L.* (*T.*) *gippslandica,* characteristic of Gippsland, where *H. semiornata* is common and *C. verriculata* exceedingly rare, with *L.* (*T.*) *batesfordensis* occurring very occasionally at the top of bore secsections. These zones will be more fully described at a later date.

Chapman (1910) made the first detailed study of the Victorian Lepidocyclinae in his work on the Batesford limestone, which led to the designation of the horizon as " Batesfordian." He recorded an assemblage of foraminifera, which, for the most part, is associated with all occurrences of *Lepidocyclina*. These forms are *Gypsina howchini, Planorbulinella plana, P. inaequilateralis* and *Calcarina verriculata*. In bores, none of these occurs above the horizon but the downwards range is extended somewhat. At Hamilton, *Hofkerina semiornata* is added to the assemblage, while in Gippsland it is very prominent but *C. verriculata* is exceedingly rare. On all occasions the above assemblage is associated with *Carpenteria proteinformis, C. rotaliformis, Amphistegina lessonii* and *Operculina victoriensis*.

Singleton (1941) considers the "Batesfordian" as a stage underlying the Balcombian, but evidence from numerous borings in Gippsland proves that it is a substage of that stage. The association of *Lepidocyclinae* with numerous mollusca referable to Balcombian species both at Hamilton in Western Victoria and at Skinner's in Eastern Victoria, the presence of the genus in Balcombian marls in the Tyabb bores, Mornington Peninsula, and its persistent occurrence in Balcombian bryozoal limestones, in subsurface sections in which no stratigraphic break is apparent, support this view.

## Age of the Lepidocyclina Horizon in Victoria.

The fact that the orbitoidal foraminifera are of such importance in zoning marine Tertiaries beyond Victoria, makes the restricted occurrence here of utmost value in determining a precise age for the beds. When Howchin (1889) described the first orbitoidal foraminifera in Victoria from Hamilton, he referred them to the Eocene genus *Orbitoides*, and for this reason beds containing such forms were recognized as Eocene for some years. Lémoine and Douvillé (1904) placed them in Eocene to Miocene genus *Lepidocyclina*. Chapman (1910) considered the limestones at Batesford to be equivalent of the Burdigalian of Southern Europe and Middle Miocene in age, on account of his record of *L. tournoueri* and *L. marginata*, while he referred the beds at Clifton Bank, Hamilton, and at Keilor to "probably Upper Aquitanian" because of his record of *L. verbeeki*, a species which is found in the Lower and Middle Miocene in the Indopacific. Present evidence points to the Keilor beds being stratigraphically equivalent to those at Batesford, with the Hamilton ones slightly lower. Chapman and Singleton (1925) stated that "the predominant development of polyzoal limestones was in the Middle Miocene-Burdigalian or Batesfordian, the typical zone fossil being *Lepidocyclina tournoueri* or *L. martini* or both." Crespin (1926) referred to the age of the *Lepidocyclina* limestone at Keilor as equivalent of the Batesfordian. Chapman and Crespin (1932) described *Spiroclypeus*, a typical "e" stage (Lower Miocene) genus from a single specimen in a limestone from the Hamilton Bore and *L. radiata* Martin from Gippsland, a species listed as belonging to "e" stage in the Netherlands East Indies, while regarding the subgenus of all species as *Nephrolepidina*. Because of this determination of *Spiroclypeus*, all *Lepidocyclina*-bearing rocks in Victoria were considered to be of Lower Miocene age (Chapman and Crespin 1935). The result has been considerable confusion. Crespin (1936) stated that the determination of the Hamilton specimen as *Spiroclypeus* was incorrect, and it was found later that *L. radiata* apparently belongs to younger beds than the Lower Miocene in the Netherlands East Indies. Crespin still placed the Batesfordian in the Lower Miocene, but suggested

that the horizon would later prove to be younger in age, because of the absence of the typical "e" stage genera *Spiroclypeus* and *Eulepidina,* and the consideration that the subgenus of *Lepidocyclina* was *Nephrolepidina* which is typically lower to middle Middle Miocene. Singleton (1941) placed the horizon of the Batesfordian in the Lower to Middle Miocene at the same time elevating it to the position of a stage directly underlying the Balcombian. This classification was followed by Crespin (1941) in a report on the Holland's Landing Bore, Gippsland, the author stating that she agreed in the main with Singleton's sequence but placed the *Lepidocyclina* beds in the Middle Miocene.

The supposition, in 1936, that the Victorian Lepidocyclinae belonged to a younger age than Lower Miocene, was confirmed by investigations carried out with Dr. Tan Sin Hok in Java in 1939, the absence of true nephrolepidine Lepidocyclinae and the exclusive presence of trybliolepidine species indicating an horizon fairly high in the Miocene.

The Burdigalian species, *L. tournoueri* and *L. marginata,* are absent, the assemblage consisting entirely of rayed forms referable to the subgenus *Trybliolepidina,* which is characteristic of the upper portion of the Miocene in the Indopacific region. *Miogypsina,* a common genus in the Miocene of the Netherlands East Indies, North-west Australia, Papua and New Guinea, is unrepresented. *Austrotrillina howchini,* which ranges from Lower to Middle Miocene in this region, occurs with *Lepidocyclina* in Gippsland and at Hamilton, the original specimen being described from the latter locality. As far as is known this form has not been recorded above the "$f_2$" stage, in the Indopacific. The species of *Cycloclypeus* recently described from Gippsland (Crespin, 1941), have close affinities with this stage.

Evidence points, therefore, to the *Lepidocyclina* horizon in Victoria being not older than Middle Miocene with indications of being high in that part of the series. It is definitely not "e" stage, and is possibly referable to basal "$f_3$" stage. In correlating it with European stages, it is higher than Aquitanian and is probably to be placed near the boundary between the Burdigalian and Vindobonian.

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## Explanation of Plates.

### PLATE III.

*Lepidocyclina (Trybliolepidina) gippslandica* sp. nov.

FIG. 1.—No. 5 Bore, P. of Glencoe, Gippsland, at 70 feet. Form A. Holotype. No. 39. × 10. (After Crespin.)

FIG. 2.—No. 15 Bore, P. of Stradbroke, Gippsland, at 45 feet. Form A. Paratype. No. 93. × 10. (After Crespin.)

FIG. 3.—No. 15 Bore, P. of Stradbroke, at 45 feet. Form A. Paratype. No. 196. × 7.

FIG. 4.—Skinner's Section, Mitchell River, Gippsland. Form A. Paratype. No. 197. × 7.

FIG. 5.—No. 15, P. of Stradbroke, at 45 feet. Form B. Paratype. No. 198. × 7.

FIG. 6.—Brock's Quarry, P. of Glencoe, Form B. Paratype. No. 199. × 7.

FIG. 7.—Brock's Quarry, P. of Glencoe, Form B. Paratype. No. 200. × 7.

PLATE IV.

*Lepidocyclina* (*Trybliolepidina*) *howchini* Chapman and Crespin.

FIG. 8.—Hamilton Bore, P. of Yulecart, Western Victoria, 80-85 feet. Form A Holotype. No. 42. × 10. (After Crespin.)

FIG. 9.—Hamilton Bore, 48-53 feet. Form A. Paratype. No. 32. × 10. (After Crespin.)

FIG. 10.—Clifton Bank, Hamilton, P. of Yulecart, Western Victoria. Form A Plesiotype. No. 201. × 8.

FIG. 11.—Hamilton Bore, 104-108. Form A. Paratype. No. 94. × 12. (After Crespin.)

FIG. 12.—Hamilton Bore, 80-85 feet. Form B Plesiotype. No. 202. × 10.

FIG. 13.—Flinders, Mornington Peninsula Form A. Plesiotype. No. 203. × 8.

FIG. 14.—Flinders, Mornington Peninsula. Form A, showing strong pustules. Plesiotype. No. 204. × 8

FIG. 15.—Flinders, Mornington Peninsula. Form B. Plesiotype. No. 205. × 8.

PLATE V.

*Lepidocyclina* (*Trybliolepidina*) *batesfordensis* sp. nov.

FIG. 16.—New Quarry, Batesford, near Geelong. Form B. Paratype. No. 206. × circ. 6.

FIG. 17.—Upper Quarry, Batesford. Form B. Paratype. No. 207. × 6.

FIG. 18.—Upper Quarry, Batesford. Form A. Holotype No. 208 × circ. 7.

FIG. 19.—Upper Quarry, Batesford. Form A, showing fractured specimen. Paratype. No. 209. × circ. 9.

FIG. 20.—New Quarry, Batesford. Form A. Paratype. No. 210. × 8.

FIG. 21.—No. 7 Bore, P. of Colquhoun, Gippsland, at 480 feet. Paratype. No. 211. × 7.

PLATE VI.

*Lepidocyclina* (*Trybliolepidina*) *gippslandica* sp. nov.

FIG. 22.—No. 5 Bore, P. of Glencoe, Gippsland, 70 feet. (Locality of Holotype.) Median section. Form A. Tectotype. No. 212. × circ. 20.

FIG. 23.—Embryonic and nepionic apparatus of Fig. 22, showing protoconchal and deuteroconchal chambers, two primary auxiliary and five adauxiliary chambers. × circ. 40.

FIG. 24.—Vertical section of specimen from same locality. Tectotype. No. 213. × circ. 20.

FIG. 25.—No. 1 Bore, Pt. Addis (Metung), P. of Bumberrah, at 872 feet. Median section. Form A, showing only three nepionic chambers. Tectotype. No 214. × 17.

FIG. 26.—Vertical section of specimen from same locality. Tectotype. No. 215. × 14.

FIG. 27.—Embryonic and nepionic apparatus of another specimen from No. 5 Bore, P. of Glencoe, 70 feet, showing protoconchal and deuteroconchal chambers, two primary auxiliary and five adauxiliary chambers. Tectotype. No. 216. × 82.

FIG. 28.—No. 15 Bore, P. of Stradbroke, Gippsland. Vertical section. Form A. Tectotype. No. 217. × 17.

FIG. 29.—No. 15 Bore, P. of Stradbroke, at 45 feet. Median section of Form B, showing rayed character of central portion. Tectotype. No. 218. × 15.

PLATE VII.

*Lepidocyclina* (*Trybliolepidina*) *howchini* Chapman and Crespin.

FIG. 30.—Hamilton Bore, P. of Yulecart, Western Victoria, 86-91 feet. Median section. Form B. Specimen ironstained. Tectohypotype. No. 219. × circ. 15.

FIG. 31.—Hamilton Bore, 36-38 feet. Vertical section. Form B. Specimen ironstained. Tectohypotype. No. 220. × 14.

FIG. 32.—Clifton Bank, Hamilton. Median section. Form A, showing embryonic and nepionic apparatus, showing protoconchal and deuteroconchal chambers, two primary auxiliary and six adauxiliary chambers, surrounded by ogival-shaped chambers. Tectohypotype. No. 221. × 53.

FIG. 33.—Hamilton Bore, 80-85 feet. (Locality of Holotype.) Median section. Form A. Tectotopotype. No. 222. × 14.

FIG. 34.—Hamilton Bore, 45-53 feet. Vertical section. Form A. Tectohypotype. No. 223. × 17.

FIG. 35.—Hamilton Bore, 80-85 feet. Median section. Form A. Tectotopotype, No. 224. × 14.

## PLATE VIII.

*Lepidocyclina* (*Trybliolepidina*) *batesfordensis* sp. nov.

FIG 36.—Old Filter Quarry, Batesford, near Geelong Embryonic and nepionic apparatus of Fig. 37, showing two primary auxiliary and six adauxiliary nepionic chambers. Tectotype. No. 225. × 120. (Photo by Dr. Tan Sin Hok.)

FIG 37.—Same locality as Fig. 36. Median section Form A. Tectotype. No. 225. × 14.

FIG 38.—Upper Quarry, Batesford, near Geelong. (Locality of Holotype.) Median section. Form A. Tectotype. No 226. × 8.4

FIG. 39.—Nepionic apparatus of Fig. 38, showing eight adauxiliary nepionic chambers. Tectotype. No. 226. × 36.5.

FIG. 40.—Upper Quarry, Batesford. Median section. Form A. Tectotype. No. 227. × 8

FIG. 41.—Same locality. Vertical section. Form A Tectotype. No. 228. × 14 5

## PLATE IX.

*Lepidocyclina* (*Trybliolepidina*) *batesfordensis* sp. nov.

FIG. 42.—Upper Quarry, Batesford, near Geelong. Median section. Form B. Tectotype. No. 229. × 7.5

FIG. 43.—Upper Quarry, Batesford. Vertical section. Form B. Tectotype No. 230. × 7 5.

FIG. 44.—Old Filter Quarry, Batesford. Median section. Form B. Tectotype. No. 231. × 16.

FIG 45 —Same locality as Fig 45. Median section Form A, showing eccentric protoconchal chamber. Tectotype. No. 232 × 50.

FIG. 46.—*L.* (*T.*) *gippslandica* sp. nov. No 1 Bore, Pt. Addis (Metung), P. of Bumberrah Median section, showing eccentric growth in deuteroconchal wall. Tectotype. No. 233. × 44.

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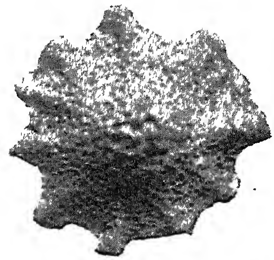

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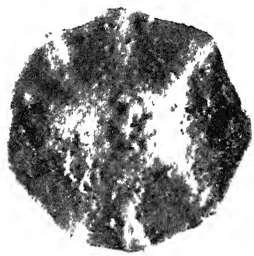

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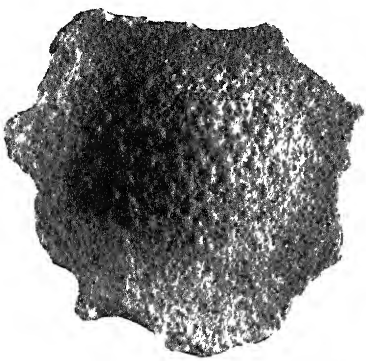

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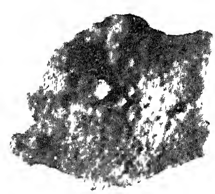

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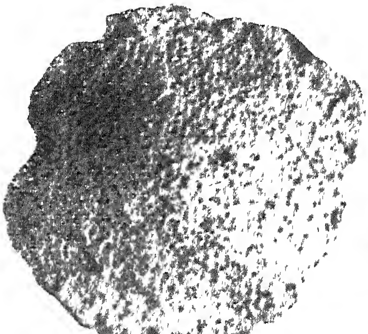

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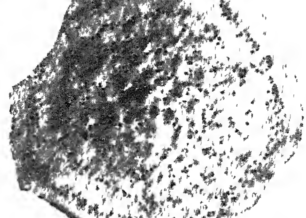

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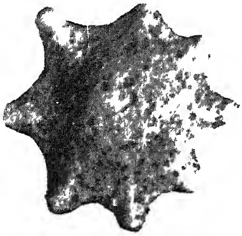

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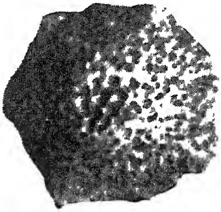

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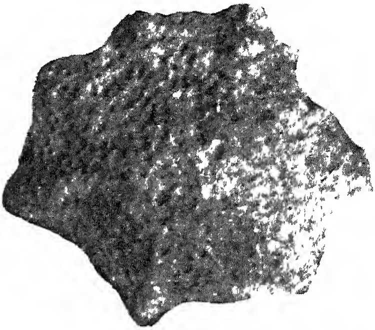

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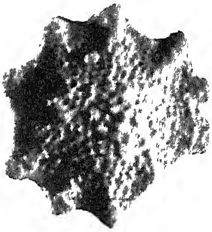

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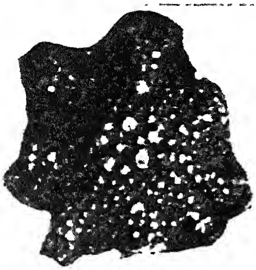

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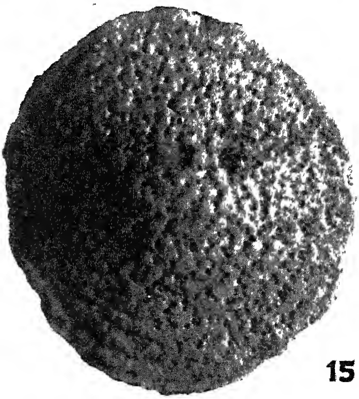

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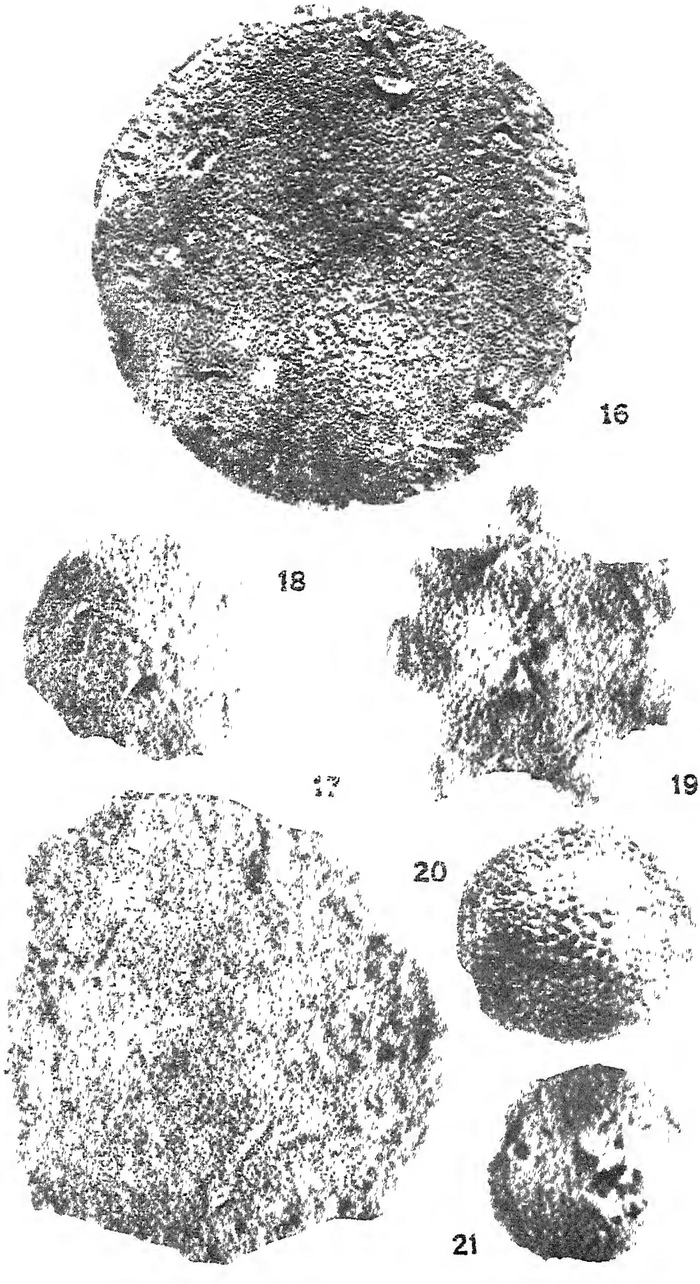
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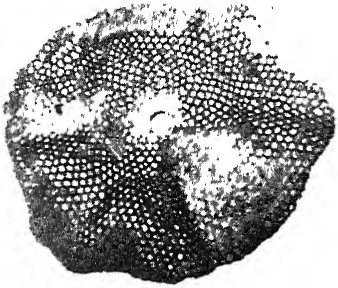

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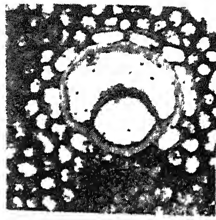

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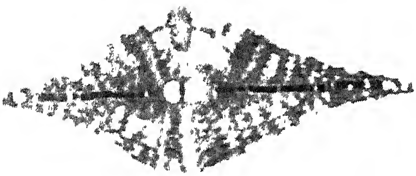

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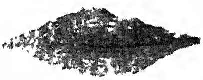

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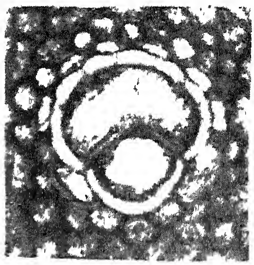

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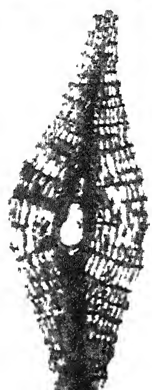

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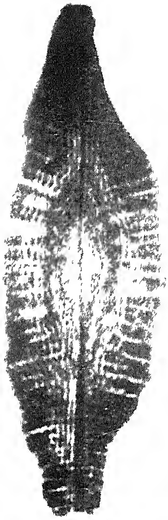

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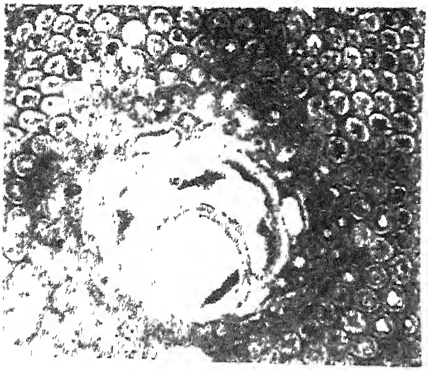

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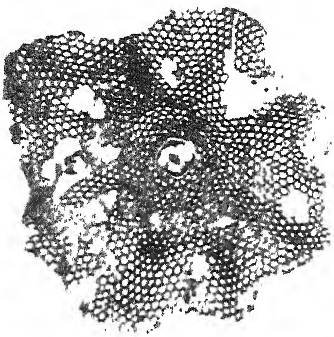

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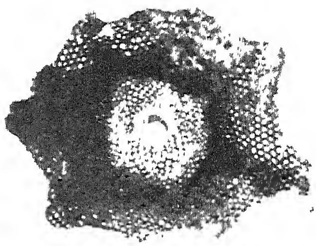

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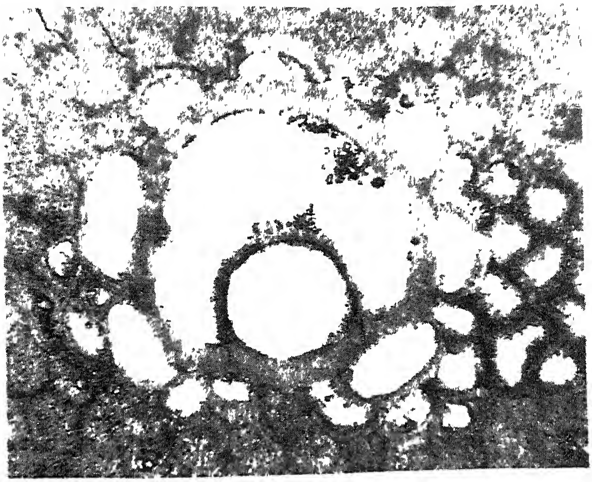

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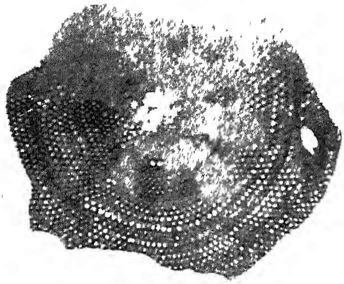

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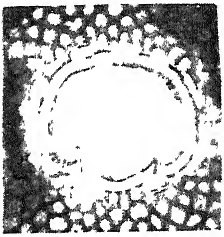

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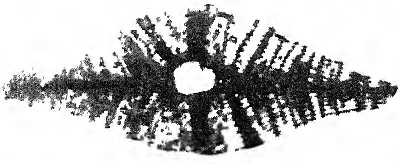

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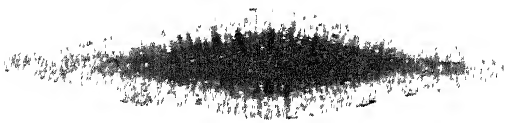

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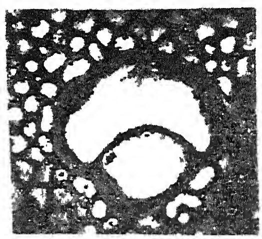

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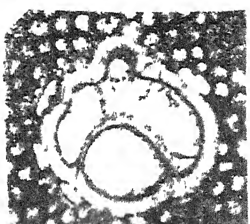

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[PROC. ROY. SOC. VICTORIA, 55 (N.S.), PT. II., 1943.]

# ART VIII.—*Jurassic Arkose in Southern Victoria.*

By A. B. EDWARDS and G. BAKER.

[Read 13th August, 1942; issued separately 1st October, 1943.]


## Abstract.

The Jurassic rocks of Victoria consist chiefly of arkoses and mudstones, with minor amounts of grit, conglomerate, and black coal, and have been derived from a terrane consisting of Palaeozoic sediments and igneous rocks (granites, granodiorites, dacites, and associated tuffs). The arkoses consist essentially of notably angular grains of quartz, oligoclase, orthoclase, biotite, and fragments of andesitic tuff, cemented together by chlorite, epidote, zoisite, and secondary felspar. Oligoclase is the dominant felspar. Calcite sometimes takes the place of the more usual cementing minerals. It often gives rise to epigenetic calcareous concretions in which it commonly replaces grains of oligoclase felspar, but not the orthoclase.

The arkoses were derived chiefly from the igneous rocks, whereas the mudstones were derived chiefly from the Palaeozoic sediments. The Jurassic mudstones differ from the Palaeozoic mudstones, however, in that they contain considerable amounts of lime and soda, and the iron in them is chiefly in the ferrous state. The iron appears to occur mostly as more or less colloidal size particles of a chlorite-like mineral.

Chloritic cement in the arkoses appears to have been deposited from the connate waters of the mudstones which migrated into the arkoses during the compaction of the sediments; and the $CO_2$ of the calcite cement is thought to have been set free during the decomposition of the plant remains that occur throughout the sediments.

The felspars in the arkoses are surprisingly fresh, and persist in a fresh condition, even in the soils derived from the Jurassic sediments. Their state of preservation does not seem to be related to the climatic conditions prevailing at the time of their deposition, because the Jurassic climate appears to have been moist and more or less temperate. The more angular felspar grains are much less decomposed than the sub-angular grains, suggesting that the freshness of the felspar is due to the fracture of coarser grains of felspar just prior to burying, rather than to the mode of weathering of the parent rocks. The subsequent preservation of the felspars was due to the sealing of the arkoses by the interbedded mudstones, while their preservation in the soils is probably due to the immaturity of the soils.


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- Chemical Analyses.
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MUDSTONES AND SHALES.

FELSPATHIC GRITS.

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COAL SEAMS AND PLANT REMAINS.
THE SOURCE ROCKS.
ORIGIN OF THE ARKOSE—
  Jurassic Climate.
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## Introduction.

The Jurassic sediments of Victoria are of fresh-water origin, and consist essentially of interbedded mudstones and felspathic sandstones, or arkoses, which commonly show current bedding, together with minor amounts of felspathic grit, conglomerate, and bituminous coal seams.

As shown on the Geological Map of Victoria, they occur in three main areas, one centering about Merino, in Western Victoria, and extending westwards to the Glenelg River, a second forming the mountains of the Otway Ranges, with a north-easterly extension in the Barrabool Hills, near Geelong, and a third forming the South Gippsland Highlands. The details of these, and other minor outcrops of the Jurassic rocks, in position intermediate between the main areas, have been published by Selwyn and Ulrich (1866), by Murray (1887), by Hunter and Ower (1914), and by Skeats (1935). The most westerly record of the Jurassic rocks is from a bore 4,504 feet deep at Robe in South Australia, in which Jurassic mudstones and thin coal seams were encountered below a depth of 1,450 feet (Ward, 1926). Their most easterly recorded occurrence is at a depth of 3,158 feet, in Bore No. 1 at Goon Nure, south of Bairnsdale (Ann. Rept. Dept. Mines, Vic., 1938, pp. 22, 40).

The estuarine or lacustrine origin of the sediments has long been recognized, but it is impossible to decide whether they were laid down in a single great estuary or lake, or in a series of large lakes, because of the extensive Tertiary earth-movements which have affected them. In the Otway Ranges the Jurassic sediments have been subjected to faulting, and possibly to warping (Hills, 1940, p. 268; Coulson, 1939), while in the South Gippsland Hills they have undergone block-faulting (Hills, 1940, p. 269) and warping (Edwards, 1942A). The uniform nature of the arkoses, and particularly the distribution throughout them of fragments of a distinctive andesite or andesite-tuff, suggest that a single basin of deposition was involved, and that the isolated nature of the present outcrops arises from the subsequent earth-movements.

The thickness of the Jurassic sediments is not known, but was estimated at 5,000 feet by Selwyn (1868, p. 19). Bores have penetrated to 3,032 feet at Coalville in South Gippsland, and to 2,804 feet at Yaugher in the Otways, without passing out of the Jurassic, and on this account Hunter and Ower (1914) also estimate the thickness of the Jurassic sediments as about 5,000 feet, making allowances for about 1,000 feet of erosion, and a possible downward extension of another 1,000 feet below the bottom of the bores.

A study of the boring records suggests that the arkose forms about 40 per cent. of the total sediments in the exposed areas. This figure has only a qualitative value, because many more bores have been put down in areas known to contain workable seams of coal than in the wider areas where the absence of such seams has been established Moreover, the thickness of individual beds of arkose and mudstone, as recorded in the bores, is often such that a bore needs to be in excess of 1,000 feet deep before it can be accepted as a reasonable sample of the proportions of the two lithological types present. The recorded range of uninterrupted thicknesses of arkose is from less than an inch up to 433 feet, and the majority of bores record one or more uninterrupted thicknesses of 100 feet, while many show an uninterrupted thickness of 200 feet. Similarly the known range of uninterrupted thicknesses of mudstone is from less than an inch up to 461 feet, but the latter figure is unusual, and uninterrupted thicknesses in excess of 100 feet are recorded in only a small proportion of the bores, while thicknesses in excess of 200 feet have been recorded only occasionally. Another difference between the arkose and mudstone beds is that successive beds of arkose may show a tremendous variation in thickness, whereas successive beds of mudstone tend to less extreme variation. This is presumably because the arkose beds are much more lenticular than the associated mudstone beds. This lenticularity, and the irregular minor folding which is often found in the Jurassic sediments, probably arise from differential compaction during lithification. (Edwards, 1942B).

The relative proportion of arkose to mudstone varies considerably in different localities, though it remains relatively constant for a restricted area. This is shown both by field studies and by the bore records. A study of the bore records, using only those in excess of 1,000 feet depth, where such exist, and averaging the proportion of mudstone and arkose obtained where more than one bore was available for a single parish, yielded some qualitative data concerning the distribution of the two rock types. The figures obtained are, however, of unequal value, because of the few bores that have been put down in the Otway and Merino areas, and because many of the bores, particularly in the Merino area, are only shallow. They indicate, however, that the arkoses

are most abundant in the southern parts of the South Gippsland Highlands and of the Otway Ranges, constituting from 60 to 70 per cent. of the thicknesses of Jurassic bored in those parishes which are probably near the southern margin of the Jurassic basin. Northwards from this margin there is a falling-off in the proportion of arkose to as little as 25 per cent.

In the Merino area, mudstone is the dominant rock (Dunn, 1912), and the evidence of all of the bores available, despite their relative shallowness, only two or three exceeding 700 feet, is that the arkose forms less than 40 per cent. of the thickness of Jurassic bores, and in most parishes less than 20 per cent., falling as low as 4 per cent. in the deepest bore (756 feet), in Muntham.

The mudstones weather much more rapidly than the arkoses (Hunter and Ower, 1914, plate 9), and where the country consists of thick formations of these two rocks interleaved with one another, the arkose formations outcrop as hills showing dip slopes and escarpments (Ferguson, 1908).

## Arkoses.

### Mineralogy.

The felspathic nature of the Jurassic sandstones, here termed arkoses, was first recognized by Selwyn (1853). The term arkose is used in the sense of Twenhofel (1932, p. 229), viz., "Arkose is a sedimentary rock composed of material derived from the disintegration of acid igneous rocks of granular texture." Brief petrographic descriptions of these rocks, from restricted localities, have been published by Richards (1910), Mahony (1922), Nicholls (1936), and Edwards (1942).

The present study is based on a collection of about 300 thin sections, largely drawn from areas in South Gippsland, but embracing the whole extent of the Jurassic outcrops. The greater proportion of this collection belongs to the Geological Survey of Victoria, the remainder being the property of the Geology Department of the Melbourne University. A noteworthy feature of the collection is that it includes sections of each successive change of lithology in four deep bores put down in South Gippsland. These are Bore No. 1 at Coalville (3,032 feet), the deepest bore in the Jurassic, Bore No. 1 at Powlett River (2,267 feet), Bore No. 1 at Berry's Creek, parish of Mardan (1,050 feet), and Bore No. 4 at Boolarra (900 feet).

The fresh arkose is characteristically greenish-grey in colour and is medium to fine-grained. The greater proportion of the grains are generally between 0·25 mm. and 0·50 mm. in diameter, and few exceed this size, though there may be a considerable number between 0·15 mm. and 0·25 mm. diameter, as is shown by Table 2. The fresh rock breaks across the grains,

showing a dull matte-like surface, faintly speckled by the light-coloured felspar grains. The green colour arises from an abundance of chloritic cement. On weathering, the rock first becomes friable, and then, as the chlorite alters to limonite, the colour changes to brown. In thin section the grains are notably angular, particularly the quartz grains. Quartz, felspars, biotite, chlorite, and fragments of andesite are the essential components. The quartz and felspars are the more important constituents. Micrometric analyses show that the quartz forms from 10 to 15 per cent. by volume and the felspars 25 to 35 per cent., the higher figures in each instance coinciding with closer packing of the grains. Some of the quartz grains carry rows of dust-like inclusions, and very occasionally they are embayed after the manner of phenocrysts in acid lava-flows.

The felspars consist of oligoclase and orthoclase with minor amounts of perthite and microcline. The oligoclase is generally more abundant than the orthoclase and is commonly clear and limpid, whereas the orthoclase is generally cloudy. Very occasionally the felspar (generally orthoclase) is graphically intergrown with quartz.

Biotite is present as scattered flakes, often twisted or broken, and showing partial alteration to chlorite. Some of it is bleached, and most of the small amount of white mica present appears to be bleached biotite. Hornblende, pleochroic from green to brownish-yellow, and more or less altered to chlorite, is occasionally present, particularly in calcareous arkoses, as though the carbonate has had a protective effect, in the manner recorded by Bramlette (1942). Even in the calcareous rocks, however, it is generally much less abundant than biotite, except at Pebble Point, on the Otway coast, where it is the dominant ferromagnesian. Pyroxenes have been found only as very occasional grains

Associated with these individual minerals, and constituting a distinct proportion of the rock, are sub-angular to rounded grains of an igneous rock. Some of these are glassy, others are micro-porphyritic, but all are of a uniform type. They consist of a fine-grained to glassy groundmass studded with microlites of a plagioclase showing almost straight extinction. In many grains the microlites show flow alignment. In others distinct micro-phenocrysts of andesine are present; and in some there are the chloritized remains of ferromagnesian minerals, so that the fragments are presumably derived from a fine-grained andesite, or an andesite tuff.

A calcareous arkose from Pebble Point contains fragments of sandstone, quartzite, mica-schist, chlorite schist, quartz schist, and what appear to be fragments of diabase tuff, in addition to the andesite fragments. Locally these rock fragments outnumber the normal mineral grains.

CEMENTING MINERALS.

The chlorite, to which the rock owes its colour occurs as irregularly-shaped patches cementing the grains together. It is apple-green in colour, and under crossed nicols appears almost isotropic or cryptocrystalline. Associated with it are irregular or idiomorphic patches of zoisite and yellow epidote. All three appear to be authigenic minerals, formed probably by the action of connate waters, during the process of lithification. Accompanying the chlorite is a little sericite, and clay material sometimes fills the interstices between grains. Staining with malachite green indicates that the clay is chiefly kaolinite.

In many sections the margins of the grains and the chlorite areas are outlined by a narrow rim of a colourless, anisotropic material. This mineral has a refractive index distinctly lower than the chlorite, and slightly lower than that of the felspars. Its birefringence is similar to that of the felspars, into which it often appears to merge. Occasionally it forms minute spherulitic growths, and in one section it was observed filling the cells of a fragment of wood. The closeness of its refractive index to that of the felspars suggests that it is authigenic albite, but it may be a zeolitic substance.

Calcite is present in small amounts in a number of thin sections as a cementing mineral; and occasionally it completely replaces the chlorite, when it may form as much as 40 per cent. of the rock. Where the calcite is abundant, there is abundant evidence that it has more or less completely replaced grains of oligoclase, although it does not seem to attack the orthoclase.

HEAVY MINERALS.

Samples of arkose from ten widely-spaced localities were examined for their heavy mineral contents, with the results shown in Table 1. Bromoform, of specific gravity 2·889, was used in the separations. As indicated by the index numbers, the heavy minerals amount to as much as 1 per cent. of the sample in only three instances. Of these, the sample from Ceres, near Geelong, and that from Griffith's Point, near San Remo, contain much material derived from the nearby Palaeozoic granites and their contact aureoles. The arkoses from localities distant from areas of granite or Palaeozoic sediments have much lower index numbers. The minerals in each assemblage are characteristically those of granitic rocks and contact metamorphosed sediments, and are closely comparable with those found in the sand fractions of soils formed from the Jurassic rocks (Nicholls, 1936). Biotite occurs throughout the assemblages as fresh or partially altered flakes, and there is a distinct relationship between the amount of biotite and the amount of apatite present in a particular assemblage. Presumably the apatite is released from the biotite during the crushing of the specimen, since similar apatite crystals

TABLE 1.—TABLE OF HEAVY MINERALS FROM SOME VICTORIAN JURASSIC ARKOSES.

| District. | Locality. | Rock. | Index Number. | Actinolite. | Apatite—clear. | Apatite—dusky | Biotite | Cassiterite. | Chlorite. | Cyanite. | Epidote. | Garnet—colourless | Garnet—pink. | Garnet—brown. | Hematite. | Hornblende. | Ilmenite | Leucoxene. | Limonite. | Magnetite. | Pyrite. | Rutile—red. | Rutile—yellow. | Sphene | Topaz. | Tourmaline. | Zircon—crystals | Zircon—waterworn grains. | Zoisite. | White Mica. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Merino . | 4 miles north of Casterton | Brown sandy mudstone | 0·1 | V | a | o | a | .. | o | V | o | r | r | r | . | V | r | r | C | o | r | r | r | o | V | C | o | . | r | r |
| Otways . | Pebble Point, Princetown | Grayish - green calcareous | 0·6 | V | . | . | r | V | r | . | o | r | o | V | o | A | C | o | V | o | C | V | . | o | | V | o | | o | V |
| | Point Hayley, Apollo Bay | Green .. | 1·0 | .. | r | .. | o | .. | C | .. | C | r | r | r | o | .. | o | r | V | o | | . | . | o | V | r | r | r | r | r |
| | Carisbrook Cr., Great Ocean Rd. | Grayish-green | 0 6 | . | o | V | C | .. | o | . | o | r | o | r | V | .. | o | r | o | .. | V | r | r | o | V | r | r | V | V | r |
| Barrabool Hills | Ceres, near Geelong | Green .. | 1·3 | . | o | V | o | V | o | .. | r | r | r | .. | o | . | o | r | r | o | V | o | .. | r | V | o | C | o | o | r |
| South Gipps-land | Griffiths Point, San Remo Pen. | Grayish-green | 1 0 | V | o | V | o | .. | A | .. | r | r | V | . | r | .. | o | r | r | . | V | r | V | r | V | r | o | . | V | . |
| | Mirboo East .. | Brown .. | 0·2 | .. | V | .. | o | V | r | .. | C | .. | .. | r | .. | .. | o | .. | o | V | .. | | . | r | . | o | o | r | V | . |
| | Middle Creek .. | Grayish - green mottled | 0·08 | .. | o | r | o | .. | a | V | o | r | V | V | .. | . | r | r | r | | | .. | | . | .. | r | o | V | r | r |
| | Stony Creek . | Brown .. | 0·08 | .. | o | V | o | V | o | V | .. | r | r | r | .. | V | .. | r | A | .. | .. | . | . | .. | . | o | V | .. | .. | r |
| | Brookleigh, Tara Valley | Green .. | 0·3 | . | o | r | C | V | C | .. | o | r | r | r | o | V | o | r | .. | . | V | .. | .. | 1 | .. | r | o | r | V | V |

*Key.*—A—very abundant; a—abundant; c—common; o—occasional; r—rare; V—very rare.

occur as inclusions in the biotite Some of the apatite crystals contain inclusions of a fibrous pleochroic material. Comparable inclusions are found in apatites in the Palaeozoic dacites at Dromana (Baker, 1938, p. 265) and at Marysville.

The preponderance of well-shaped zircon, tourmaline and rutile crystals over water-worn grains suggests that the bulk of these minerals has been derived direct from igneous rocks, but the occasional water-worn grains may have come from older sediments. The ilmenite has a fresh appearance, and shows only partial alteration to leucoxene.

The epidote and zoisite, as might be expected from their mode of occurrence in the thin sections, show no signs of water-wear. The garnets, of which there are three varieties, brown, pink, and colourless, occasionally show signs of water-wear. Some of the garnet grains are surprisingly large, despite the fact that they were separated from crushed rock. Anatase was met with as only very occasional grains in the Casterton sample, although Nicholls (1936) has recorded it from the sand fractions of soils from all three of the main Jurassic areas.

### Mud Pellets.

A number of the sections contain small rounded pellets of mudstone, which range in size up to a centimetre in diameter. Occasionally these pellets are so crowded together that the arkose appears as a cement filling the interstices.

### Wood Fragments.

Fragments of coalified wood are present in a number of the sections, including some from the deep bores. Not infrequently these fragments are sufficiently well preserved to show the patterns of the cell structure of the wood.

## Sizing Analyses and Particle Shape.

Five samples of arkose were used for sizing studies. Of these, four were selected on account of their abundant carbonate cement, which made it possible to break down the rock by treatment with dilute acid, and so preserve the shapes and sizes of the grains. The fifth sample was a friable rock, easily broken down in water with a minimum of grinding. The samples were taken from three widely separated localities, and at two of the localities two samples were taken, a little distance apart in the same bed. The results obtained by screening these disintegrated rocks through sieves are set out in Table 2. They show that the rocks are medium to fine-grained, and that the degree of sorting is uniform within a given bed, but varies greatly from bed to bed, some rocks consisting of well-sorted grains, others of poorly-sorted grains.

TABLE 2.—SIZING ANALYSES OF JURASSIC ARKOSES.

| Fractions | +0·5 mm | +0 25 mm. | +0·15 mm. | −0 15 mm. | Clay. |
|---|---|---|---|---|---|
| Pebble Point, Princetown, residue of calcareous arkose, 40 per cent carbonate .. .. | 0·4 | 81·4 | 9·6 | 3 1 | 5·5 |
| Bourne Creek, Kilcunda, friable arkose . | 2·3 | 66·0 | 17 2 | 10·8 | 3·7 |
| Bourne Creek, Kilcunda, residue of calcareous concretion, 25 per cent. carbonate . . | . | 59·6 | 23 8 | 15·8 | 0·8 |
| Tarra Valley, South Gippsland, calcareous concretion, 45 per cent. carbonate .. . | .. | 36·8 | 30·6 | 24·7 | 7·9 |
| Tarra Valley, South Gippsland, residue of calcareous concretion, 49·3 per cent. carbonate | .. | 38·5 | 31·2 | 25·2 | 5·1 |

Mounts of these various sized fractions revealed that in every instance the mineral grains were predominantly angular to subangular. Rounded grains were rare. The quartz grains were chiefly angular, with occasional subangular grains. The felspars tended to be tabular cleavage fragments, and showed rather more rounding, angular and subangular grains being present in about equal proportions. The subangular grains of felspar were generally cloudy, while the angular grains were almost always clear. A number of grains both of quartz and felspar were wedge-shaped splinters, with fine points, while others had delicate points or protrusions on their corners, so that, while they may have been fractured during transport, they cannot have undergone a great deal of abrasion.

The ferromagnesian and other heavy minerals were concentrated in the —0·15 mm. fraction. The abundant hornblende of the Pebble Point rock, the hornblende and biotite of the Tarra Valley rocks, and the biotite of the Kilcunda rocks, were all concentrated in this fraction. This, no doubt, is a result of sorting during transport, the greater specific gravity of these ferromagnesian minerals causing smaller grains of them to be associated with coarser grains of quartz and felspar. The occurrence of the heavy minerals in this fraction is due, no doubt, to their original occurrence as small crystals.

POROSITY.

Measurements of absorption capacity range from 2 per cent. by weight for fresh rocks, to 10 per cent. for weathered rocks. Low absorptive capacity is associated with high FeO content,

while high absorptive capacity is associated with low or negligible FeO content, so that the increase in porosity with weathering arises from a volume shrinkage of the cement as the chlorite changes to limonite.

## Chemical Analyses.

Comparison of the analyses of typical arkoses (Table No. 3) with available analyses of Palaeozoic sandstones from Victoria emphasizes the unusual composition of the arkoses. Their richness in alkalies and alumina, and their low silica contents, reflect their richness in felspars, while the dominance of soda over potash, and the abundance of lime, mark the preponderance of oligoclase over orthoclase. Variations in the individual analyses show that the total volume of felspar in the arkoses varies considerably from one locality to another, and that the relative proportion of orthoclase to oligoclase is equally variable, except that oligoclase is always the more abundant of the two. The plentiful chlorite in the arkoses is responsible for the unusually high FeO and MgO contents. In those analyses in which $Fe_2O_3$ dominates FeO, the samples were taken from weathered, brown rock, in which the chlorite is largely altered to limonite.

Table 3.—Analyses of Jurassic Arkoses.

| — | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ .. .. | 65·50 | 64·13 | 64·00 | 63·60 | 62·18 | 61·92 | 61·04 | 57·90 | 57·57 |
| $Al_2O_3$ .. .. | 15·49 | 18 59 | 15·88 | 16·38 | 17·13 | 15·75 | 16·06 | 18·76 | 17·96 |
| $Fe_2O_3$ .. .. | 0 36 | 1·99 | 1·90 | 0·97 | 0·87 | 3·12 | 2·57 | 4·20 | 4·27 |
| FeO .. .. | 4 24 | 1 78 | 3·86 | 3·81 | 4·05 | 2·53 | 4·61 | | |
| MgO .. .. | 1 92 | 1 24 | 1·81 | 1·92 | 2·60 | 2·47 | 2·55 | 1·31 | 1·51 |
| CaO .. .. | 3·50 | 1·34 | 2·02 | 2·15 | 2·19 | 2·13 | 1·92 | 3·40 | 1·38 |
| $Na_2O$ .. .. | 2·60 | 4·36 | 3·42 | 4·19 | 2·15 | 2·76 | 2·00 | 2·88 | 2·64 |
| $K_2O$ .. . | 1·96 | 1·98 | 1·86 | 1 89 | 1·57 | 1·89 | 1·00 | 0·98 | 1·73 |
| $H_2O+$ . | 1·89 | 3·43 | 3·84 | 3·02 | 0·96 | 4·05 | 4·13 | 3·65 | 5·37 |
| $H_2O-$ .. | 0·54 | 1·38 | 1·04 | 1·18 | 3·31 | 1·78 | 1·90 | 4·35 | 6·57 |
| $CO_2$ .. .. | 1·65 | tr. | nil | tr. | 1·32 | .. | .. | 1·77 | 0·50 |
| $TiO_2$ .. .. | 0·60 | . | .. | 0·69 | .. | 0·81 | 0·87 | 0·81 | 0·72 |
| $P_2O_5$ .. .. | 0·20 | .. | .. | 0·12 | .. | .. | 0·35 | .. | .. |
| MnO .. .. | 0·06 | tr. | tr. | 0·09 | .. | .. | 0·25 | .. | .. |
| | 100·51 | 100·22 | 99·63 | 100·01 | 98·33 | 99·21 | 99·25 | 100·21 | 100·22 |
| $Na_2O/K_2O$ .. | 1·33 | 2·20 | 1·84 | 2·22 | 1·37 | 1·46 | 2·00 | 2·94 | 1·53 |

1. Arkose, cliff opposite Brookleigh, below the weir, Tarra Valley, near Yarram, South Gippsland; *Analyst*: A. B. Edwards.
2. Arkose, from McCann's Quarry, Ceres, Barrabool Hills; *Analyst*: H. C. Richards, *Proc. Roy. Soc. Vic.*, n.s., xxii, p. 194, 1909.
3. Arkose, from Apollo Bay, Otway Ranges; *Analyst*: H. C. Richards, *Ibid.*
4. Arkose, from Griffith's Point, San Remo, South Gippsland; *Analyst*: A. B. Edwards.
5. Arkose, from Apollo Bay, Otway Ranges; *Analyst*: P. G. W. Bayley, Rept. on Geol. Sheet A.47. *Spec. Rept. Dept Mines*, 1901.
6. Arkose, from Craigleith Quarry, Pettavel Road, Barrabool Hills; *Analyst*: P. W. G. Bayley.
7. Arkose, near Coal Creek, Korumburra, South Gippsland; *Analyst*: P. G. W. Bayley.
8. Arkose, from No. 5 bore, State Coal Mine, Wonthaggi, South Gippsland; *Analyst*: F. F. Field.
9. Arkose, from dump in the Dudley Area, State Coal Mine, Wonthaggi, South Gippsland; *Analyst*: F. F Field.

Another feature revealed by the comparison is the distinctly uniform $SiO_2$ and $Al_2O_3$ content of the arkoses as compared with the considerable range shown by these constituents in the more normal sandstones.

In Table No. 4 are shown the analyses of several arkoses in which the chloritic cement of the normal arkose has been more or less completely replaced by calcite, the culmination of this replacement being calcareous concretions (Table No 4, Analysis No. 4), in which the carbonate content of the arkose rises as high as 50 per cent. of the whole. In these rocks the proportions of FeO and MgO remain unchanged, despite the absence of chlorite. In weathered specimens the ferrous carbonate has been converted to limonite. The unusually high MgO content of Analysis No. 3 in Table No. 4 suggests that some magnesium carbonate was introduced into the rock along with the calcium carbonate. Similarly the high MnO contents of the specimens showing most carbonate (Analyses Nos. 3 and 4 of Table No. 4) indicate that some manganese carbonate accompanied the calcium carbonate.

TABLE 4.—ANALYSES OF CALCAREOUS ARKOSES.

| —— | 1. | 2. | 3. | 4. |
|---|---|---|---|---|
| $SiO_2$ .. .. .. | 55·15 | 52·90 | 44·67 | 41·58 |
| $Al_2O_3$ .. .. .. | 15·23 | 16·49 | 13·57 | 10·93 |
| $Fe_2O_3$ .. .. . | 4 49 | 0·78 | 4·87 | 2·40 |
| FeO .. .. .. | 0·98 | 4·86 | 2·76 | 1·89 |
| MgO .. .. .. | 2·79 | 2·92 | 3·82 | 1·30 |
| CaO .. .. .. | 5·43 | 7·14 | 9·97 | 21·06 |
| $Na_2O$ .. .. | 1·16 | 2·58 | 1·18 | 1·86 |
| $K_2O$ .. . . | 1·65 | 1·73 | 1·53 | 1·83 |
| $H_2O+$ .. .. .. | | 2·93 | . | 0·71 |
| $H_2O-$ . .. .. | 1 90 | 1·72 | 1·92 | 1·39 |
| Ignition Loss .. . | 11·00 | . | 15·16 | .. |
| $CO_2$ .. .. . | . | 4·65 | | 14·93 |
| $TiO_2$ . . . | 0 59 | 1·10 | 0·52 | .. |
| $P_2O_5$ . . . | tr | 0·25 | tr. | . |
| MnO .. . .. | 0·22 | tr. | 0·62 | 1·60 |
| Cl .. .. | . | tr. | | .. |
| $SO_3$ .. . .. | nil | nil | nil | .. |
| | 100·59 | 100·05 | 100·59 | 101·48 |
| $Na_2O/K_2O$ .. . | 0·70 | 1·49 | 0·77 | 1·01 |

1. Calcareous arkose, allotment 76, parish of Longwarry, near Lang Lang River, South Gippsland; *Analyst*: F. F. FIELD, *Rec. Geol. Surv. Vic.*, 4, Pt. 4, 451.
2. Calcareous arkose, old shaft of Coal Creek Proprietary Mine, Korumburra, South Gippsland, *Analyst*: P. G. W. BAYLEY.
3. Calcareous arkose, allotment 74, parish of Longwarry; *Analyst*: F. F. FIELD, *Rec. Geol. Surv. Vic.*, 4, Pt. 4, 451.
4. Calcareous concretion in arkose (some manganese carbonate), Apollo Bay, Otway Ranges. *Analyst*. P. G. W. BAYLEY, *Spec. Rept. Dept. Mines, Vic.*, 1901 (Report on Geol. Sht. No. A. 47).

(Host rock, Analysis No. 5, Table 1.)

In three of these analyses (Nos. 1, 3, and 4, of Table No. 4) the $Na_2O$ content is considerably lower than in any of the normal arkose analyses, being equalled or surpassed by the $K_2O$ content. This confirms the evidence of the thin sections that the oligoclase

in these rocks tends to be replaced by the calcite, while the orthoclase is not affected. Such replacement is not invariable, however, since in the fourth analysis (Analysis No. 2 of Table No. 4) the alkalies appear normal.

This variable behaviour of the carbonate on the felspars is further demonstrated by alkali determinations on the sand fractions of three of the rocks used in the sizing analyses (Table 2), namely, the residue of a calcareous concretion from near Brookleigh Farm, in the Tarra Valley, from which 49·3 per cent. of carbonate material had been leached with dilute hydrochloric acid; the residue of a calcareous concretion from near the mouth of Bourne Creek, at Kilcunda, from which 25 per cent. of carbonate had been leached; and the untreated fractions of a friable arkose from Bourne Creek, at Kilcunda. The alkali contents of the various fractions are shown in Table No. 5.

TABLE 5.—ALKALI CONTENTS OF SIZED FRACTIONS OF ARKOSES.

| Fraction. | $K_2O$. | $Na_2O$. | $Na_2O/K_2O$. |
|---|---|---|---|
| 1. *Residue of Tarra Valley Concretion.* | | | |
| +0·25 mm. | 4·21 | 2·03 | 0·48 |
| +0·15 mm. | 4·93 | 2·02 | 0·41 |
| −0·15 mm. | 4·62 | 2·55 | 0·55 |
| 2. *Residue of Kilcunda Concretion.* | | | |
| +0·25 mm. | 2·48 | 3·50 | 1·41 |
| +0·15 mm. | 2·02 | 3·20 | 1·57 |
| −0·15 mm. | 1·77 | 2·50 | 1·33 |
| 3. *Friable Arkose from Kilcunda.* | | | |
| +0·25 mm. | 2·19 | 3·16 | 1·44 |
| +0·15 mm. | 1·76 | 2·71 | 1·54 |
| −0·15 mm. | 1·39 | 2·01 | 1·44 |

The figures show that in the Tarra Valley rock a large proportion of the oligoclase has been replaced by calcite, while in the Bourne Creek concretion, little or no replacement of oligoclase has taken place. This is confirmed by the appearance of the felspars in thin sections of the two concretions.

Another feature of these partial analyses is that the total amount of felspar in the two Bourne Creek specimens diminishes as the grain size of the fraction decreases. This feature is not shown by the Tarra Valley specimen, but is probably true of the sediments as a whole, since thin sections show that the proportion of felspars in the sandy mudstones is always much less than the proportion of felspars in the arkoses. The figures indicate, however, that there is no significant or progressive variation in the ratio of potash to soda in the various sized fractions of a particular rock, so that apparently the comminution and destruction of both orthoclase and oligoclase proceeded at equal rates, and was not selective.

## Concretions.

### Calcareous Concretions.

Many of the arkose beds are characterized by calcareous concretions which are spherical, or less commonly, dumb-bell shaped. Their average diameter is between 3 and 6 inches, though some are larger. They are of epigenetic origin, since the bedding planes of the enclosing arkose pass through them without interruption. Occasionally these lines of stratification, as noted by Daintree (1862), are marked by films of coalified leaf remains. In the hand specimen the concretions appear identical with the enclosing arkose, but being harder, they project from weathered surfaces, especially cliff-faces and wave-cut platforms. They are generally structureless, though occasionally when weathered they break into concentric shells.

Thin sections show them to consist of the normal arkose minerals cemented together by coarse-grained crystals of calcite, the calcite sometimes invading and replacing the oligoclase. A typical concretion from arkose at Apollo Bay, in the Otway district, was found by V. R. Stirling (1901) to contain about 30 per cent. of calcite (Table No. 4, Analysis No. 4), while the enclosing arkose contained only 3 per cent. of calcite (Table No. 3, Analysis No. 5). That this is characteristic is shown by the fact that three concretions selected at random, two from the Tarra Valley, and one from Kilcunda, were found to contain 49·3 per cent., 43·5 per cent., and 25·0 per cent. of carbonate, respectively. In each instance the enclosing rock contained only a few per cent. of calcite cement.

The concretions do not occur in the shales or mudstones, and their restriction to the arkose is related to the higher porosity of these rocks. Presumably the concretions mark centres of slow crystallization of calcite from solutions filling the pore spaces of the arkose. The calcium carbonate in the adjoining rock was able to diffuse from all sides through the pore spaces to the widely spaced centres of crystallization, where it crystallized as a spherical meshwork of carbonate enclosing the mineral grains of the rock, at the same time converting the existing chlorite cement to carbonate. Insufficient carbonate was left in the surrounding rock to give it comparable hardness or bonding.

In other arkose beds calcite is present in abundance (Table No. 4, Analyses Nos. 1, 2, 3), but concretions have not formed. Either conditions did not permit diffusion to localized centres of crystallization, and crystallization occurred rapidly about many centres, or the supply of calcium carbonate was so great that the early-formed concretions continued to grow until the whole bed was cemented. The relatively small amount of carbonate in some of the beds, compared with the large amount in the concretions, suggests that the first explanation is the more probable. In places,

however, there was an excess of carbonate available, and it formed veins of calcite, sometimes several feet thick.

PYRITIC CONCRETIONS.

In the Apollo Bay district, Stirling (1901) noted small pyritic concretions in the arkoses, presumably of similar general origin to the calcareous ones. Such concretions do not appear to be numerous in other Jurassic areas. At Wyelangata, also in the Otway area, however, small nodules of pyrite and veins of pyrite and calcite, carrying as much as 2 dwt. of gold per ton, occur in the bedding planes of mudstone beds (Easton, 1935). Pyrite, associated with calcite, is also found in thin films in the joints of coal seams at Kilcunda.

QUARTZ VEINS.

Stirling (1899) records the occurrence of thin quartz veins, carrying felspar, in the Jurassic near Mount Sabine.

## Mudstones and Shales.

The mudstones and shales are generally blue or grey in colour, turning buff or brown on weathering. When rich in carbonaceous matter they are black. Like the arkoses, they are commonly current bedded. They range from sandy mudstone, containing numerous small angular fragments of quartz and a little felspar, in a fine-grained matrix of sericite and clay, to extremely fine-grained rocks in which little other than sericite can be made out with the microscope. The quartz grains, when present, are often wedge-shaped and sharp pointed. The proportion of felspars in the coarser mudstones and shales is always much less than that found in the arkoses, but both orthoclase and oligoclase are present. In the majority of mudstones examined there is an abundance of shreds and fibres of woody material, all the fibres lying parallel to one another and to the bedding planes, so they often reveal the presence of current bedding even in the finest grained sediments. This abundance of wood fibres indicates that broken-down plant remains were being supplied continually to the Jurassic basin of sedimentation.

The clay matrices of several samples were extracted, and tested by staining with malachite-green and saffranine-o, both before and after treatment with hydrochloric acid (Faust, 1940). This showed that in addition to kaolinite the clays contained a considerable proportion of a mineral or minerals subject to base exchange. A partial analysis of the composite fine clay remaining in suspension after twelve hours, from a typical blue mudstone from Cape Paterson, gave the results shown in Analysis No. 6, Table No. 6. Since as much as one-third of this material consisted of kaolinite, the mineral showing base exchange must be an iron-rich variety containing relatively little alumina.

It differs, however, from all the iron-rich clay minerals in that the bulk of its iron is in the ferrous state, whereas in the iron-rich clays the iron is in the ferric state. That this is general in the Jurassic mudstones is shown by the dominance of ferrous iron over ferric iron in their analyses (Table No. 6). This is in equally striking contrast to the state of the iron in the more normal Palaeozoic slates and mudstones in Victoria in which the iron is chiefly in the ferric state. According to Grim (1939), the common clay mineral of such rocks is illite. The clay-like mineral in the Jurassic mudstones, however, must be more akin to a chlorite in a very finely divided state.

When the analyses of the mudstones (Table No. 6) are compared with those of the arkoses (Table No. 3), considerable resemblances are noted, and certain differences. The $SiO_2$ content of the mudstones is much the same as that of the arkoses, and

TABLE 6.—ANALYSES OF JURASSIC SHALES.

| —— | 1. | 2. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|---|
| $SiO_2$ .. .. | 61·36 | 60·70 | 59·72 | 57·83 | 57·40 | 53·57 |
| $Al_2O_3$ .. .. | 18·18 | 18 32 | 19 26 | 18·49 | 20·44 | 18·05 |
| $Fe_2O_3$ .. .. | 4·26 | 1 18 | 0 80 | 0 41 | 1·14 | 1·95 |
| $FeO$ .. .. | . | 3·18 | 3·06 | 1·79 | 2·44 | 13·35 |
| $MgO$ .. | 1·26 | 2·02 | 1·92 | 1·59 | 1·50 | 2 81 |
| $CaO$ .. .. | 1·68 | 2·00 | 0·82 | 1·53 | 0·98 | nil |
| $Na_2O$ .. . | 1·94 | 1 25 | 1 44 | 1·52 | 1·41 | 1·16 |
| $K_2O$ .. . | 3·32 | 2·64 | 4·17 | 2·42 | 3·66 | 2·09 |
| $H_2O+$ .. .. | 4·23 | 4 13 | 5·01 | 7·72 | 5·99 | . |
| $H_2O-$ .. | 3·10 | 3·35 | 3·50 | 5·32 | 3·63 | .. |
| $TiO_2$ .. .. | .. | 0·90 | 0·99 | 0 63 | 0·90 | 0·60 |
| $P_2O_5$ . .. | .. | tr. | tr | nil | tr | |
| $Cl$ .. .. | .. | tr. | nil | tr. | nil | .. |
| $SO_3$ .. .. | .. | nil | tr. | tr. | nil | .. |
| | 99·33 | 99 67 | 100·69 | 99·25 | 99·49 | .. |

1 Shale from the roof of the Outtrim Colliery, South Gippsland; *Analyst*: F. E. A. STONE, *Ann. Rept. Sec. Mines*, 1898, p. 28.

2 Shale from above coal seam, east adit near shore, Kilcunda; South Gippsland; *Analyst*: P. G. W. BAYLEY, *Ann. Rept. Sec. Mines*, 1906.

3. Shale from above seam in Coal Creek Mine, Korumburra, South Gippsland; *Analyst*: P. G. W. BAYLEY.

4. Shale forming the seatstone in coal mine, Kilcunda, South Gippsland; *Analyst*: P. G. W. BAYLEY, *Ann. Rept. Sec. Mines*, 1906.

5. Shale from under coal seam in Coal Creek Mine, Korumburra; *Analyst*: P. G. W. BAYLEY, South Gippsland.

6. Composite clay fraction remaining in suspension after 12 hours, from blue Jurassic mudstone, Cape Paterson; *Analyst*: A. B. EDWARDS.

shows much the same range of variation. The $Al_2O_3$ content of the mudstones is a little higher than that of the arkoses of corresponding $SiO_2$-content. Lime, magnesia and iron oxides are present in much the same amount, and alkalies are still abundant; but whereas $Na_2O$ is the dominant alkali in the arkoses, $K_2O$ is dominant in the mudstones. In this respect the Jurassic mudstones and shales approach more closely to their Palaeozoic equivalents, which are dominantly potassic (Howitt, 1923), than do the arkoses. The consanguineous relationship between the

mudstones and the arkoses is shown, however, by their $Na_2O$ and CaO contents, which are unusually high for such rocks, and arise from the abundance of plagioclase in their source material.

A minor but interesting difference between the arkoses and the mudstones, is the relative abundance of $P_2O_5$ in the arkose, in contrast with its relative absence from the mudstones. The $P_2O_5$ in the arkose occurs in small apatite crystals enclosed in biotite flakes, and with the increased comminution of the biotite flakes these apatite crystals were set free and then dissolved.

The mudstones, like the arkoses, have a relatively uniform composition, and hence a much more restricted range of composition than is shown by the normal Palaeozoic mudstones and slates.

## Felspathic Grits.

Thin beds of felspathic grit occur at a number of places along the Otway and South Gippsland coasts, and in the Barrabool Hills. They are most prominently developed at San Remo, where they outcrop in the vicinity of Griffith's Point, and along the Western Port coast of the peninsula (Edwards, 1942B). Small pebbles of granite, arenaceous sandstone, shale, and slate are intermingled with the grit. The material is clearly derived from the nearby granite of Cape Woolamai, and the sediments of its contact aureole. Felspar has been separated from the quartz during deposition, so that quartz predominates in the grit. An alkali determination on a specimen practically free from mica and pebbles gave the values $K_2O$ 1·99, $Na_2O$ 1·39, as compared with $K_2O$ 4·76, $Na_2O$ 3·00, in the granite (Summers, 1914). The ratio of potash to soda in the grit is not significantly different from that in the granite, so that there has been no differential winnowing of orthoclase or oligoclase from the quartz during the formation of the grit, but merely of felspar from quartz. Where the grits are calcified, the calcite is found replacing the oligoclase in the grit, but not the orthoclase.

At Apollo Bay the grits occur as thin beds and lenses interstratified with arkose, as at San Remo, and again consist chiefly of granitic material with quartz grains preponderating. There are no outcrops of granite in the vicinity, but the character of the grits suggests that granite must occur somewhere nearby, either beneath the Jurassic sediments, or under the sea.

In the Barrabool Hills, similar grits are exposed at Buckley's Gorge, on the Barwon River (Coulson, 1930), where they are interbedded with arkoses, and with thin beds of conglomerate carrying granitic and other boulders.

The heavy minerals obtained from these grits are set out in Table No. 7. They are of a granitic nature. The zircons in both grits examined include both prismatic and water-worn forms, the

water-worn zircons being the less numerous. The apatite crystals sometimes have coloured, pleochroic cores, like those found in Victorian granites (Baker, 1941). Some of those in the Apollo Bay grit contain inclusions of a fibrous pleochroic material. The ilmenites show partial alteration to leucoxene.

TABLE 7.—HEAVY MINERALS IN JURASSIC GRITS.

| Mineral. | San Remo. | Apollo Bay. |
|---|---|---|
| Apatite | r | o |
| Biotite | r | a |
| Bleached Biotite | C | o |
| Chlorite | o | o |
| Epidote | .. | r |
| Garnet | r | r |
| Hornblende | .. | V |
| Ilmenite | o | o |
| Limonite | a | .. |
| Magnetite | .. | o |
| Rutile | V | r |
| Sphene | V | r |
| Tourmaline | r | o |
| Zircon | o | o |
| Zoisite | .. | r |

*Key.*—a—abundant; o—occasional; C—common, r—rare; V—very rare.

## Conglomerates.

Two types of conglomerate occur in the Jurassic rocks; (1) those containing pebbles drawn from the Jurassic terrane, and (2) those in which the pebbles are all derived from earlier deposited Jurassic mudstones and arkoses. The greatest known development of the first type of conglomerate is exposed along the Tyer's River in South Gippsland, where it marks the boundary between the parishes of Tanjil East and Boola Boola (Murray, 1876; Whitelaw, 1899). Cliff sections along the eastern side of the Tyer's River show more than 100 feet of conglomerate resting unconformably on the Silurian, and dipping at from 5 to 12 degrees south. The conglomerate consists of well-rounded large and small pebbles of hard Silurian sandstone, quartzite, and quartz, in a sandy matrix, with a cement of iron oxide. Some indication of bedding can be seen in the conglomerate, with which are intercalated sandy and shaly patches, sometimes carrying plant remains. To the south the conglomerates pass beneath normal arkose and shale beds.

A similar conglomerate is exposed in the banks of Rintoul's Creek, to the east, but it is not so thick at this locality, and contains smaller pebbles of somewhat softer Silurian rocks.

Conglomerates with pebbles of pre-Jurassic rocks occur at a number of other localities, both in the Otways and in South Gippsland, but they nowhere else attain such a volume. Along the Otway coast they have been recorded as thin beds and lenses, associated with grits and arkoses, from Pebble Point (Wilkinson,

1864) and Castle Cove (Kitson, 1900). In the Barrabool Hills, they are exposed at Buckley's Gorge, on the Barwon River, near the local base of the Jurassic (Daintree, 1861; Wilkinson, 1864; Coulson, 1930). Marginal conglomerates, up to 3 feet thick, occur interbedded with grits and arkoses at Griffith's Point, near San Remo on the South Gippsland coast (Stirling, 1892; Ferguson, 1908; Edwards, 1942). Similar conglomerates occur in the Jumbunna district, where they form beds about 10 feet thick (Kitson, 1917).

Some of the Jumbunna pebbles are polished, and Kitson suggests they are derived from Permian (Permo-Carboniferous) glacial conglomerate beds.

At Chitt Creek, near Toora, Ferguson (1906) has described a lenticle of somewhat similar conglomerate at the junction of the Silurian with the overlying Jurassic. The pebbles consist of granite, resembling that of Wilson's Promontory, indurated sandstone and grit, chert, quartzite, felsite, and siliceous shale. Some of the pebbles were polished, striated and facetted, while others were not. Ferguson suggested that this conglomerate bed, which is about 3 feet thick, is of glacial origin, but Kitson (1917) is of the opinion that this and similar conglomerates in the Jurassic may be derived from resorted glacial beds of Permian age. Mahony (1930) classes this conglomerate and similar basal conglomerates underlying the Jurassic at Coleraine as of Permian (Permo-Carboniferous) age.

Isolated pebbles and boulders of foreign origin are sometimes found in the mudstones and arkoses, being more numerous in the coarser-grained sediments. Ferguson (1906) records the occurrence of two large boulders of granite near Kilcunda, while Hunter and Ower (1914) describe a pebble of granophyric granite found in the roof of No. 5 coal seam at Wonthaggi. Near Anderson's Inlet there are highly-polished pebbles of felsite, mica-schist, jasper, agate, carnelian, quartzite, quartz, sandstone, and silicified wood in the arkoses (Kitson, 1903). Felsite has been recorded from Waratah Bay (Stirling, 1894), but the other rocks are foreign to the district.

The second type of conglomerate, in which the pebbles all consist of Jurassic mudstone and sometimes arkose, and even coal, is of more frequent occurrence, but rarely exceeds a length of 20 feet, or a thickness of more than a foot. Kitson (1917) has described such conglomerates in the Jumbunna district, where he found pebbles and boulders of mudstone ranging in size from 2 inches by ½ inch up to 7 or 8 feet by 2 or 3 feet. In some rounded mudstone " boulders " over a foot in diameter he found well-preserved plant remains and casts of *Unio*. In other beds there were numerous rounded to sub-angular pellets of mudstone, many of them flattened and oval shaped. Some of these

may have been "mud curls." Conglomerates of this type are exposed along the San Remo coastline (Edwards, 1942), and at Cape Paterson (Ferguson, 1908), along the Otway coast (Wilkinson, 1864; Kitson, 1900), and in the Barrabool Hills (Coulson, 1930). They are well developed in places in the roofs of the coal seams in the Wonthaggi State Coal Mine, where they form lenses 1 to 3 feet thick, extending over areas of an acre. They clearly arise from contemporaneous erosion of the Jurassic beds, and sometimes have themselves suffered erosion soon after deposition. Kitson (1917) describes such an occurrence in the Jumbunna district, where pebbles of coal in such a conglomerate have been partially eroded, and fresh arkose beds deposited on the eroded faces of the pebbles.

## Coal Seams and Plant Remains.

Thin seams of black coal occur at a number of places in the various Jurassic areas, but workable seams are restricted to a belt about 50 miles long and 10 miles wide, running north-east from Kilcunda (Hunter and Ower, 1914). The individual seams are lenticular, and extend over only small areas. The best seams average between 2 and 3 feet thick, occasionally attaining thicknesses of as much as 9 feet, and they are generally much faulted. The coal is worked in the State Coal Mine at Wonthaggi (Platt, 1940), and in smaller mines at Kilcunda, Korumburra and Jumbunna. The coal at Korumburra and Jumbunna is of higher grade than that at Wonthaggi and Kilcunda, suggesting that there was a greater thickness of sedimentary cover in this part of South Gippsland.

Most workers have considered that the coal is of drift origin (Selwyn, 1853; Murray, 1895; Stirling, 1895; Kitson, 1917). The evidence cited in favour of such an origin is the absence of old soils beneath the coal seams; the occurrence of seams with both floor and roof consisting of arkose, or with a floor of arkose; the presence of current bedding in the rocks forming the roof and floor of the seams; the presence of quartz pebbles in the coal at Korumburra and Jumbunna, unaccompanied by any sandy material; the presence of fossil branches, roots, and tree trunks in the arkose beds, in positions in which they could not have grown. Hunter and Ower (1914), on the other hand, consider that the coal vegetation grew *in situ,* but offer little evidence in support of their belief.

The surface of the coal-forming peat was subject to contemporaneous erosion, since small washouts filled with arkose occur in the Kirrak and Shaft 18 areas of the State Coal Mine at Wonthaggi. One such washout in the Kirrak area failed to cut to the base of the coal seam, and is overlain by a 2-inch thick band of dirt (arkose) above which is about 12 inches of good

coal. In this area of the mine the roof of the seam consists of arkose, sometimes showing current bedding and containing waterworn pebbles. Occasionally it gives place to runs of fine conglomerate.

The coal is bituminous, and is generally very finely banded, the individual bands or lenses of coal being as thin as 0·01 inch. Vitrain forms only a small proportion of these bands, the bulk of them consisting of dull coal. Occasionally, however, bands of vitrain occur as wide as 0·5 inches. Banding in coal is generally regarded as due to fluctuations in the water conditions of the swamp in which the coal vegetation grew (White, 1932), but there is a possibility that in these seams it might be due to deposition of drifted material. In a number of localities the arkoses occur as thin beds, often less than a centimetre thick, each bed separated from the next above by a thin layer of coalified leaf remains and wood fragments. Several hundred such beds may be exposed in a few feet in a single cutting. Deposition of the wood fragments without the intervention of the thin beds of arkose could well have given rise to a thin coal seam.

### Plant Remains.

No doubt can be entertained of the drifted nature of fragmentary plant remains just described, nor of the small twigs and branches of coalified wood found along the bedding planes of the arkose beds at many localities. Further evidence of drift is provided by the countless fibres of woody matter found in the mudstones.

The plant remains occurring in the arkose beds are generally fragmentary and waterworn, but well preserved, and often delicate, leaf remains are found in the mudstones. The Jurassic flora has not been studied exhaustively, but sufficient work has been done to reveal its general nature (Seward, 1904; Chapman, 1908, 1909; Stirling, 1900). It resembles the flora of the estuarine phase of the Yorkshire Oolite. There is a tendency for one or two species to predominate at any given locality, but they do not appear to be restricted to any particular horizon in the Jurassic, nor to provide a basis for zoning the deposits.

The only other fossils recorded are an occasional *Unio* (Selwyn, 1866; Stirling, 1900; Kitson, 1917), a few fossil fish (Etheridge, 1902; Woodward, 1907; Chapman, 1908), and the claw of a carnivorous Dinosaur (Woodward, 1907).

## The Source Rocks.

By definition, the composition of an arkose is a direct reflection of the composition of the rocks from which its constituents are derived, and where the arkose extends over a wide area, it may be expected to show local variations in accordance with the changing nature of its terrane.

Such relationship appears to hold for the Jurassic sediments in Victoria. The Jurassic terrane consisted predominantly of Palaeozoic sediments, chiefly of Ordovician and Silurian age, and of Palaeozoic granitic rocks, porphyritic extrusives, and tuffs, with much less extensive outcrops of Cambrian sediments and epidiorites, of Carboniferous sandstones and shales, and of Permian tillites and glacial sandstones; and it is possible to trace, in some degrees, the contribution which each made to the Jurassic basin of sedimentation.

The clearest evidence of the origin of the source material is provided by the pebbles in the marginal conglomerates and grits of the Jurassic, which are largely derived from nearby Palaeozoic igneous rocks and sediments, as for example at the Barrabool Hills, where the Jurassic conglomerate contains pebbles of the nearby Heathcotian epidiorite, and of granite and contact metamorphosed Palaeozoic sediments, or at Tyers River, where the boulders consist essentially of Silurian sediments. Further evidence is provided by the marked difference in mica content between the Palaeozoic sediments and the Jurassic sediments. In the Palaeozoic sediments, especially those of Silurian age, muscovite is the predominant mica (Langford, 1916; Dunn, 1921), whereas it is a relatively uncommon mineral in the Jurassic rocks. In the Jurassic rocks, biotite is the dominant mica, and the bulk of the small amount of white mica present appears, from its specific gravity, which exceeds 2·889, to be bleached biotite. This predominance of biotite in the Jurassic rocks can only be attributed to the fact that biotite is the dominant, and often the sole, mica in the Palaeozoic granitic and extrusive rocks in the vicinity of the Jurassic sediments. The biotite, both in the Jurassic rocks and in the Palaeozoic igneous rocks, is characterized by inclusions of apatite crystals. Moreover, the hornblende which sometimes accompanies, or more rarely takes the place of, the biotite, is closely comparable with the hornblende found in certain of the Palaeozoic granitic rocks.

A small proportion of the felspar in the Jurassic arkoses may have come from the Palaeozoic sediments, since the Silurian sandstones contain a small proportion of fresh oligoclase (Junner, 1913; Langford, 1916) and the Ordovician carries small amounts of weathered orthoclase and oligoclase (Dunn, 1921), but the bulk of it was probably derived from the Palaeozoic igneous rocks. The excess of oligoclase over orthoclase in the arkoses is difficult to explain in terms of present exposures. Most of the orthoclase, and a large part of the oligoclase must have been drawn from the granitic rocks, considerable areas of which are hidden by the waters of Bass Strait, and the basalt plains of Western Victoria. These comprise granites, adamellites, and granodiorites. The relative proportions of the three are unknown, but it is unlikely that the granodiorite is sufficiently preponderant to account for the

whole of the oligoclase in the arkoses. Micrometric analyses of the granitic rocks (Baker, 1942) show that, taken as a whole, they are not likely to contain more than about 30 per cent. by volume of oligoclase to 25 per cent. of orthoclase, and the $Na_2O/K_2O$ ratio for such of them as have been analysed ranges from 0·67 to 1·42, while for the arkoses it ranges from 1·33 to 2·94, the average for nine analyses being 1·88. Part of the $Na_2O$ in the arkoses occurs, of course, in fragments of andesite or andesite-tuff and as authigenic albite, but even so their $Na_2O$ content could scarcely be accounted for by the granitic rocks unless they consisted predominantly of granodiorite.

Some proportion of the felspar in the arkoses came from the extensively eroded dacites and rhyodacites of Dromana (Baker, 1938), and the Dandenong Ranges (Richards, 1909; Morris, 1914). In the majority of these rocks oligoclase phenocrysts greatly outnumber orthoclase phenocrysts, sometimes to their complete exclusion, as in the hypersthene-dacites of the Dandenong Ranges, in which oligoclase phenocrysts constitute about 25 per cent. by volume of the rock. Whether a sufficient volume of oligoclase could have been obtained from the original outcrop of these rocks, and whether it could have been spread so uniformly through the wide extent of Jurassic sediments from these centralized sources is open to considerable doubt. The difficulty can be overcome only by assuming, as do Hunter and Ower (1914, p. 195), that closely similar rocks occurred in the requisite volume in association with the granitic rocks that are known to exist beneath the waters of Bass Strait. Quartz-felspar-porphyry, or rhyodacite, closely resembling the Victorian rhyodacites, occurs in the south-eastern part of King Island, in the vicinity of the Bismuth Products mine.

Some proportion of the oligoclase may have been drawn from the same source as the fragments of andesite or andesite-tuff that are so characteristic of the Jurassic arkose beds. The source of these fragments cannot be established with assurance, but the available evidence suggests that they come from flows of andesite, or beds of andesite-tuff associated with the Upper Devonian dacites. It was suggested earlier (Edwards, 1942) that they represented tuff fragments falling into the Jurassic lake, but it was not realized then how uniformly the fragments are dispersed throughout the arkoses. Moreover, there is no evidence of contemporaneous igneous activity in this part of Australia. The Mesozoic igneous activity which gave rise to the great dolerite intrusions in Tasmania did not, apparently, lead to the formation of extrusive rocks. These intrusions did not develop until at, or near, the close of the Trias-Jura sedimentation in Tasmania, and, in view of the undifferentiated nature of the dolerite magma at the time of its intrusion (Edwards 1942c), it is most unlikely that it could have given rise to andesitic tuffs or lava flows.

The probability is, therefore, that the andesite fragments were derived from extrusive rocks or tuff beds associated with the Upper Devonian dacite suites, and it is significant in this connection that they can be matched with practically identical andesite fragments in a thick bed of tuff recently discovered along the eastern margin of the hypersthene-dacites of the Dandenong Ranges. This tuff bed, which is as yet undescribed, dips steeply towards the south-west, and apparently underlies the hypersthene-dacite. The steep dip indicates that a considerable volume of it has been eroded. Fragments of this andesite are abundant in the Lower Dacite flows at the northern end of the Dandenong Ranges, and fragments of somewhat comparable andesite are numerous in the rhyodacites of the Black Spur district (Edwards, 1932), so that there is some reason for thinking that rocks of this type may have been as widespread as the other Upper Devonian extrusive rocks with which they are associated.

The markedly greater potash content of the Jurassic mudstones and shales, compared with that of the arkoses, cannot be attributed to selective destruction of the oligoclase and concentration of orthoclase in the residue with increased comminution of the felspar grains, because the analyses of the sized fractions of the arkoses show that this did not happen (Table 5). It is rather a reflection of the contribution made by the Palaeozoic sediments to the Jurassic lake. The Ordovician and Silurian sediments, which make up the great bulk of these rocks, consist of sandstones, mudstones, shales and slates, with very occasional beds of limestone and conglomerate. The material from the sandstones, being largely quartz, served chiefly as a diluent to the felspars from the igneous rocks. Material from the mudstones, shales and slates must, however, have joined the more finely comminuted material from the igneous rocks, and since the fine-grained Palaeozoic sediments are dominantly potassic (Howitt, 1923), it follows that the marked increase in the potash content of the Jurassic mudstones relative to that of the arkoses is a reflection of the differential distribution of the sedimentary source material. Whereas the arkoses reflect chiefly the igneous aspect of the Jurassic terrane, the mudstones reflect chiefly its sedimentary aspect.

It is probable that the Permian tillites and glacial sandstones also contributed material to the Jurassic lake, but, since these rocks do not differ greatly in essential constituents from the other Palaeozoic source rocks, the extent of their contribution cannot be estimated. That they did contribute is suggested, however, by the nature of the garnets in the Jurassic rocks. The smaller, colourless and pink garnets in the arkoses probably came from the Lower Palaeozoic sediments, since these carry such garnets (Langford, 1916). Many of the colourless and pink garnets in the arkoses are distinctly larger, however, than those in the

Ordovician and Silurian sandstones, and these must have been derived from the Palaeozoic igneous rocks (Edwards, 1936; Baker, 1942), or from the Permian sediments (Scott, 1937), in which similar coarse garnets occur. The brown garnets of the arkoses have been matched only in the Permian sediments, and in the igneous erratics that accompany them, in the Bacchus Marsh district, where they have been noted in heavy mineral mounts prepared by Scott, though not recorded by him. The other possibility is that such garnets were derived from the rocks from which the erratics were drawn.

## Origin of the Arkose.

Owing to the readiness with which felspars decompose when exposed in humid climates, an abundance of more or less fresh felspar in a sedimentary rock is commonly taken as an indication that the sediment was formed under arid or glacial conditions, such as would inhibit chemical weathering of the felspar during the breakdown of the parent rock and during transportation (Mackie, 1899). It is recognized that arkoses can be formed under the conditions of moist and temperate climates, but such arkoses have been thought to be of secondary importance only, and to be characterized by partially decomposed felspars (Barton, 1916).

This view of the relationship of felspars to climate has been challenged, however (Reed, 1928). The proportion of felspars in the arkoses deposited throughout the Cainozoic period in California has been found to remain unchanged, despite the gradual change of the climate of that region from a humid sub-tropical climate during the Eocene to a sub-boreal, semi-arid climate in the Pliocene, so that the long continued deposition of arkoses was independent of the climate (Reed, 1933). The preservation of the felspars in arkoses formed under humid climates is attributed to rapid deposition of the felspathic sediment, so that the felspars in it are "sealed" from further decomposition (Hatch, 1938).

### The Jurassic Climate.

Sussmilch (1941) has suggested that the climate of Eastern Australia during the Jurassic period was not greatly different from the present climate. The evidence in Victoria is somewhat scanty. Absence of any stratigraphical break in the Jurassic implies the continued existence of an extensive fresh-water lake or estuary throughout the period of sedimentation, and hence a rainfall adequate to maintain such a water body. The abundant presence of plant remains, whether they grew in the hinterland, or in swamps in the lake, is further evidence of a moist climate; and the combination of ferns and coniferous trees that make up the flora suggests a moderate rather than an extreme temperature.

The possibility that glacial conditions existed during the early stages of the Jurassic sedimentation has been suggested by Ferguson (1906) to account for a supposedly Jurassic glacial conglomerate near Toora, in South Gippsland, but this view has been discounted on the grounds that this inextensive conglomerate, and some others elsewhere in the Jurassic, may be re-sorted Permian glacial deposits (Kitson, 1917). The presence of floe-ice has been envisaged as the transporting agent of the sporadic foreign pebbles found in the arkoses and sometimes in the mudstones (Kitson, 1917) ; but floating vegetation may have been responsible for their carriage. Moreover, the presence of *Ceratodus* and of large *Unios* in the sediments points to warm rather than cold conditions.

The abundant flora and coal seams of the Upper Triassic of Tasmania (Nye and Blake, 1938) suggest that the climatic conditions during this period were not greatly different from those of the Jurassic. Somewhat drier conditions may have prevailed, however, during the preceding stage of the Triassic, since local deposits of rock salt and epsomite are found in the Ross Sandstone series of Tasmania.

There is little, therefore, to suggest that the climate was sufficiently arid, or sufficiently cold, to greatly inhibit the decomposition of the felspars in the Jurassic terrane; and this finds support from the state of the felspars themselves, since a proportion of them are cloudy from partial decomposition, even in the freshest rocks.

## The Conditions of Deposition.

The prominence of current bedding in the arkoses, and, to a somewhat less extent in the mudstones, leaves little doubt that they were " formed in shallow water under the influence of strong and constantly changing currents " (Selwyn, 1866, p. 18). The boring records show that the current bedding is characteristic throughout the explored thickness of the Jurassic. This feature led Murray (1884, p. 84) to suggest that some of the arkoses might be of wind-blown origin, but the angularity of the mineral grains disposes of this possibility.

The depth of water fluctuated since the sediments were subject to contemporaneous erosion. The top-set portions of current bedded arkoses were sometimes truncated, and previously formed beds, particularly of mudstone, were eroded, with the formation of conglomerates in which the pebbles consist chiefly of Jurassic mudstone. Occasionally, these " contemporaneous " conglomerates were eroded in their turn. Even the coal was subject to erosion, since some of these conglomerates contain pebbles of coal. If the interpretation of some of the mudstone pellets as " mud curls " is correct, the bed of the lake must have been exposed

from time to time in some parts. The occurrence of washouts in the coal seams at Wonthaggi also points to this, as do occasional current ripple marks found in the State Coal Mine.

The preservation of the mud pellets and pebbles in the "contemporaneous" conglomerates suggests that they were rapidly reburied; otherwise such soft, recently-formed material would have been worn down to its component grains. The rapid alternation of extremely thin beds of arkose with films of plant remains also points to rapid deposition, and so does the well-preserved appearance of delicate fern fronds in some of the mudstones. Again, in many pieces of silicified wood, the grain is often beautifully preserved, suggesting that the wood was quite undecomposed when buried. This seems the more probable since in one specimen from Jumbunna the wood appeared to have undergone partial decay before silicification (Kitson, 1917).

Fresh Felspar.

The angular nature of the mineral grains, and the fact that even in the arkoses the individual grains are considerably smaller than those found in the Palaeozoic granitic rocks, shows that the mineral grains have been fractured during transport. Such fracturing probably accounts for the presence of the abundant grains of fresh felspar. Chemical weathering of a felspar crystal extends from the surface inwards, so that if a large crystal is fractured, some of the fragments that result may consist of fresh felspar. These fragments will then begin to weather at the surface in their turn. This seems to be what has happened in the Jurassic arkoses. As the examination of the sized fractions of the arkoses showed, in each fraction the angular, and presumably freshly broken, grains of felspar were clear and limpid, while the sub-angular grains, which had undergone more prolonged transport since being fractured, were generally cloudy from decomposition. It would appear, therefore, that angular fragments of fresh felspar can occur in a sediment quite independently of the climate under which the sediment was formed.

The angularity of the grains also indicates that the sediments suffered relatively little wear during transportation, or alternatively that transportation was not prolonged. The relatively fresh state of preservation of biotite, which is regarded as one of the chemically less stable minerals (Twenhofel, 1932, p. 226), is a further indication that the sands did not undergo prolonged transportation, though in view of recent work on the stability of minerals such evidence must be treated with caution (Russell, 1939, p. 44).

Such evidence as can be obtained points then to relatively rapid deposition in shallow waters subject to current action. This, combined with the interleaving of mudstone with arkose,

resulting from fluctuating depth of water, would provide the necessary conditions for the formation of a "sealed deposit" in which fresh felspars might be preserved.

## Diagenesis.

The carbonate cement of the calcareous arkoses was clearly introduced after the deposition of the sediments; and since the interstratification of the arkose beds with mudstone must have "sealed" them from surface waters, it seems likely that the carbonates were deposited from the connate waters in the sediments. Presumably the carbon dioxide was obtained from the plant remains during their decomposition or carbonization, while the lime was largely derived from comminuted plagioclase, since the carbonate readily attacked the oligoclase. The pyrite nodules and veins may have had a somewhat similar origin, since pyrite and calcite occur together in the joints of the coal. The sulphur of the pyrite may have been set free as hydrogen sulphide during the decomposition of plant remains, in which pyrite is unusually abundant.

The chlorite cement, with its associated zoisite, epidote and (?) albite, was also formed, no doubt, after the deposition of the sands, from substances in solution in the connate waters. The ferromagnesian minerals in the arkoses generally show partial alteration to chlorite, but they are not as abundant as the chlorite cement. The felspars, on the other hand, are often fresh and angular, so that they have not undergone much alteration or solution *in situ,* except where attacked by calcite. It seems, therefore, that while some of the cementing material may have been derived from the minerals in the sands, a considerable proportion of it must have been introduced from the muds, the finest clay fraction of which has been shown to be rich in a chlorite-like substance. Presumably as the muds became increasingly compacted, the water in them migrated into the more persistent pore spaces of the sands, and there deposited material carried in solution.

The abundance of springs and seepages in the South Gippsland Highlands and in the Otways district indicates that on exposure the arkose beds serve as channel-ways for underground waters. The felspars in such beds are little affected by the passage of the water. Two reasons can be advanced to explain this. Firstly, the abundant chlorite in the rock is more susceptible to attack than the felspar, so that the chemical activity of the water may be neutralized before it greatly affects the felspars. Secondly, the oxidation of the chlorite by the surface waters tends to convert it into limonite, which will form a protective coating about the felspar grains. There is no change in the MgO content of the

rocks during this alteration of the chlorite to limonite, so that presumably the MgO, with the $SiO_2$ and $Al_2O_3$ of the chlorite, enters into clay minerals.

Even in the soils formed on the Jurassic rocks the felspars persist in abundance, and many of the grains are in a relatively fresh condition (Nicholls, 1936). It was thought that the felspars in the soils might be protected from weathering by a film of iron oxide, the residue of the original chloritic cement, but this is not so, and it seems likely, as Nicholls (1936) concluded, that either the potash and soda felspars are more stable than is generally believed, or more probably, that the Jurassic soils are so immature as to be little more than crumbled rock—crumbled through decay of the cement—and that soil erosion is so rapid as to remove the soil before the felspars can decompose *in situ*.

## The Jurassic Terrane.

Any attempt to reconstruct the Jurassic terrane must take into account the prominent development of fresh-water felspathic sandstones, or arkoses, in the Upper Triassic of eastern Tasmania (Nye and Blake, 1938, pp. 45-49). These rocks closely resemble the Jurassic arkoses of Victoria, both in their mode of occurrence, association, and mineral composition. The similarity extends even to the presence in them of fragments of andesite-tuff such as characterize the Victorian rocks. It seems highly probable that both series of arkoses derived much of their material from the same general source, namely, a land-mass that is now sunk beneath Bass Strait. As the numerous granitic islands in the Strait indicate, this land-mass must have been largely composed of granitic rocks, with associated Palaeozoic and older sediments. There must also have been extensive areas of dacites and andesite-tuffs similar to those now outcropping in Victoria, and to a more limited extent in north-eastern Tasmania.

There has been some tendency to think that the two series of arkoses were formed simultaneously, despite the different character of their flora; but such an assumption is not justified, since both series of sediments were marginal to the same land area, and would reflect its composition equally, even though the basins in which they were deposited were formed at somewhat different times.

These basins apparently underwent slow, but continued, subsidence, because the sediments that filled them are of a shallow water character throughout. In Victoria, a subsidence of the order of 5,000 feet keeping pace with deposition is required. In Tasmania a similar, though earlier, subsidence of not less than 2,000 feet is required, since the total thickness of the arkoses and the associated Ross Sandstones and Upper Sandstones is of this order (Nye and Lewis, 1928; Nye and Blake, 1938).

The land occupying Bass Strait was probably mountainous. This is indicated by the mountainous nature of Wilson's Promontory, and the likelihood that many of the islands in the Strait are the tops of submerged mountains.

The limits of the Jurassic basin cannot be ascertained, but where its floor has been encountered around the margin of the present outcrops, it commonly slopes steeply, and appears to have considerable relief. At Griffith's Point, near San Remo, the Jurassic sediments are known to persist to more than 850 feet below sea-level, while a mile away the Cape Woolamai granite, which is apparently part of the same fault block (Edwards, 1942), rises to 300 feet above sea-level. This granite contributed much of the material in the Jurassic rocks now exposed at sea-level. Either the Eastern Passage separating the two formations marks the site of a pre-Tertiary Older Volcanic fault, or there is a fall of more than 1,150 feet in the floor of the Jurassic basin in a distance of 1 mile.

In the parish of Kongwak, an island of Silurian rocks outcrops at 420 feet above sea-level (Kitson, 1917), while a bore a mile to the north-west penetrated to about 600 feet below sea-level, without encountering the Silurian. Bores near Wonthaggi, and along the Powlett River, suggest that the Silurian outlier in Kongwak is part of a Silurian ridge trending south-westwards from this point. In these bores (Ann. Rept. Sec. Mines, 1917, Plate iv.), the Silurian occurs at depths ranging from 322 feet (Bore No. 681, Wonthaggi) to 1,311 feet (Bore No. 175, Wonthaggi), while other bores as deep as 2,633 feet (Bore No. 9, Powlett River) on either side of the ridge have failed to encounter the Silurian. The variable depths at which the Silurian occurs is due in part to faulting. Comparable inliers of Palaeozoic sediments occur at Turton's Creek (Ferguson, 1925) and at Boolarra (Ferguson, 1917) in South Gippsland.

South-west of Foster, the Palaeozoic sediments of the Hoddle Range rise to a height of 1,000 feet at Bald Hill, while their contact with the Jurassic rocks a mile to the north and north-west is at from 300 to 500 feet above sea-level. Near Lavers Hill the fall is 250 feet in a quarter of a mile.

On the northern margin of the Jurassic rocks in South Gippsland, the base of the Jurassic is about 450 feet above sea-level where it overlies the Silurian along Tyers River. A quarter of a mile to the north the Silurian rocks rise as high as 800 feet, and about 2 miles to the north they reach 1,000 feet above sea-level.

Along the Otway coast, at Apollo Bay, grits derived from a not far distant granite occur at sea-level, while bores at Wild Dog Creek, 2 miles away, penetrated more than 1,470 feet of

Jurassic sediments without encountering the underlying rocks. Faults may be present in the intervening country.

Elsewhere the floor of the basin may have sloped more gently. Thus, on Phillip Island, the Silurian lies beneath the Jurassic at a depth of 460 feet below sea-level at Rhyll, and of 306 feet at Cowes, 4 miles to the west, while on the other side of the island at Pyramid Rock, which is 5 miles south of Cowes, granite and Palaeozoic sediments rise about 50 feet above sea-level.

The Jurassic basin appears to have been a long narrow trough, not less than 350 miles, and probably more than 450 miles, long, with a width somewhat in excess of 50 miles. It had an uneven floor, which may have been as mountainous as its hinterlands. Deeper or quieter waters prevailed in the west where there is a greater development of mudstones, and along the central part of the basin. The floor of this basin subsided to a depth of about 5,000 feet, sufficiently slowly to maintain shallow water conditions throughout the whole period of deposition. In the early stages, a number of islands occurred in the lake or estuary, but as subsidence progressed these islands were buried by the accumulating sediments. The continued subsidence accounts for the steepness of shorelines like that between Griffith's Point and Cape Woolamai.

The waters of the basin were subject to strong and changing current action over most of its area—an unusual feature for a lake, though perhaps not for a shallow estuary. There seems, however, to be a complete absence of any gradation into marine beds, both in the Victorian Jurassic and in the Tasmanian Triassic. There is also a lack of current ripple-marks, though such ripple-marks were observed in the roof of the main roadway of the Shaft 18 area of the State Coal Mine.

Slow subsidence, and an adequate rainfall, combined to bring material to the basin in a fairly fine state of subdivision, chiefly as sands and muds. There is a surprising lack of marginal conglomerates, and of quartzose grits, but this may be due to inadequate exposure, and to erosion. In the Tasmanian Triassic a series of basal grits and conglomerates from 50 to 100 feet thick is recognized, but the only approach to this series in Victoria is the development of conglomerates between Tyer's River and Rintoul's Creek. The continued rejuvenation of streams feeding into the basin lead to rapid erosion of the hinterlands, and caused the felspars from the disintegrating igneous rocks to be carried into the waters of the basin before they had time to decompose greatly by weathering. Once in the lake they were rapidly sorted and dispersed by wave and current action, and were soon buried beneath later additions of sediment. From time to time, when subsidence temporarily failed to keep pace with sedimentation, they were subjected to local re-erosion and deposition by the lake waters.

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# Art. IX.—*Phenomenal Colonization of Diatoms in Aqueducts.*

By A. D. HARDY.

[Read 12th November, 1942; issued separately 1st October, 1943.]

## Abstract.

An algal infestation of aqueducts of the Melbourne and Metropolitan Board of Works supply occurred in 1941 and has, seasonally, recurred between cleansing operations. The algae were chiefly diatoms. In one of the channels which was affected for many miles, the diatomaceous growth appeared on the cement walls as an oyster-coloured, felt-like stratum and comprised about a dozen species of which a few were dominant. In parts the felt was composed exclusively of the diatom *Gomphonema oxycephalum* Cleve. var. *subacuta,* var. n.

The cause of this phenomenal colonization in a hitherto unaffected, 12-year old aqueduct has not been satisfactorily determined, but it is suggested that much carbon and ash entered the highland streams during the forest fires of 1939 and, with the silica resulting from the subsequent erosion, afforded an abundance of shell building material for the diatoms.

In the Spring of 1940 the open channels of the Melbourne and Metropolitan Board of Works Water Supply became infested with an abnormal growth of algae of which, especially in one channel, the greater part was almost wholly diatomaceous. The walls of the channel became covered with a felted stratum for miles; and this was replaced by new growth after cleaning operations by the Board's officials, or the natural peeling from the cement. The daily clearance of accumulations of masses involved labour diverted from other urgent work and on that account the growth was objectionable, but, otherwise, little inconvenience was caused, and no discomfort was experienced by consumers.

As the channels of the several aqueducts affected were those below their respective storage reservoirs, excepting one instance to which reference will be made, and not the inlet channels, a brief description of the four reservoirs is given.

## The Reservoirs.

The water supply for the reticulation of Melbourne and suburbs is obtained from the forested southern slopes of the Dividing Range, where the average annual rainfall is between 50 and 60 inches. The reservoirs—Yan Yean, Maroondah, O'Shannassy, and Silvan—all receive water from tributaries of the Yarra River; but Yan Yean receives via Toorourrong reservoir a supplementary supply diverted from the north side of the range.

1. The Yan Yean system comprises (*a*) Yan Yean reservoir which has its local catchment on Silurian formation; (*b*) Toorourrong reservoir, which receives water directly from tributaries of the Plenty River; the catchment area being part granite and part Silurian; (*c*) the supplementary supply from the north side of Mt. Disappointment where tributaries of King Parrot Creek are tapped at Silver Creek weir, and Wallaby Creek dam. The water is then gravitated to a saddle in the range, and descends to Toorourrong by a series of cascades and the natural course of Jack's Creek. This diverted water is from granitic formation.

Yan Yean reservoir has a capacity of 6,250 million gallons and an altitude of about 600 feet. A monthly collection of algae from this reservoir by the author in 1905-6 has been described by G. S. West (1).

2. Maroondah reservoir has an altitude of approximately 460 feet and has a dacite catchment area of about 40,000 acres. Its storage capacity is approximately 6,274 million gallons.

3 O'Shannassy reservoir, with a capacity of 930 million gallons, is at an altitude of about 1,200 feet, and collects water from the watershed of the Ligar River (originally " Bellell "). The greater part of this 32,000 acres is dacite. At the southern (lower) end of the catchment there is a small area of Silurian rocks. The highest point of the watershed is Mt. Arnold (4,300 feet). A few miles below the dam the O'Shannassy water is supplemented by water conveyed along an open channel and a siphon from McVeigh's where the Upper Yarra catchment is a Silurian area. Unlike Yan Yean and Toorourrong, but resembling Maroondah, the O'Shannassy reservoir is bounded by steep slopes to the water's edge, and shows a comparative paucity of phytoplankton and an almost complete absence of littoral host plants for the harbourage of diatoms and other algae.

This water flows in open channels and siphons about 22 miles to Silvan reservoir, with the addition of some from Corranderrk Creek in the Maroondah area.

4. Silvan reservoir is held by a dam 2,100 feet long and 140 feet high at an altitude of about 800 feet in the Dandenong Range. The local catchment is a dacite area of about 1,200 acres. The reservoir stores from this, and the borrowed O'Shannassy and Maroondah quotas, some 8,800 million gallons. The highest part of the local watershed is less than 2,000 feet. From the north end of Silvan, where the inlet and outlet are only about ½ mile apart, the mixed water is conducted by open channel and siphon about 5 miles to the Olinda service reservoir, at altitude 670 feet, and thence by underground pipes to various reservoirs and the reticulation.

## The Aqueducts.

With the exception of siphons, the Board's aqueducts are cement-faced channels, varying in cross-section both in shape and area, but a brief description of the O'Shannassy-Silvan-Olinda channel at a point above the Silvan Inlet will serve, as the variations are immaterial in the present connexion. The cemented walls slope up from a 9 feet wide bottom at an angle of 45°, providing for a water depth of about 4 feet and a freeboard of 9 inches as at full flow on one date of inspection; the flow being then at the rate of 3·1 feet per sec. The channel is provided with wooden gratings in which the openings are from about ½ in.–1 in. wide, set at an angle of about 30° from the horizontal, for the arrest of twigs, leaves and other forest debris, at siphon entrances, &c. At the pipe-head reservoir a further arrest is made on copper screens, the wires of which are about ·5 mm. apart.

The rate of flow, mentioned above, was sufficient to float innumerable fugitive masses of the algal felt, usually below the surface, to the gratings, where the larger masses were held. Others passed through, and on to Silvan reservoir where some sank, a few were caught on twigs, &c., and the remainder, passing through the north end of this reservoir, entered the Silvan-Olinda section, where, with the exception of very small fragments, they accumulated 5 miles down on the wire screen. A few fragments passed into the reticulation and clogged the meters.

The quality of the water which passed over miles of the felt was unaffected. The exclusively diatomaceous material was odourless and tasteless, tough and "gritty" between the teeth. Even when a mass was crammed into a jar, with only sufficient water to cover it, there was no objectionable odour after weeks or even months of stagnation. If drained and enclosed in a partially air-tight vessel, however, the material became maladorous within 24 hours. Material with considerable inclusions of green algae soon putrified in similar confinement. When dried, this oyster-coloured diatomaceous felt lost about 85 per cent. of its weight and assumed a greyish-green colour (due to loss of the camouflaging diatomin revealing the chlorophyll).

## The Algae of the Channels.

In all the channels there are normally, between times of cleaning operations and especially in spring and early summer, species of *Spirogyra, Zygnema, Mougeotia, Ulothrix,* and, but more noticeable in that of Maroondah than the others, *Oedogonium* spp. The Zygnemaceae have not been collected in fruiting condition, cleaning of the channels anticipating the spore formation. The bright green streamers in the current attain a length of 12 inches or

more, usually in a zone with limits approximately 6 inches and 24 inches below the surface. These streamers of filamentous algae strain from the water many small chlorophytes, diatoms, flagellates, &c. Myxophytes also abound in places, appearing as dark-green velvet-like patches extending from about 9 inches below the surface to some inches above, the aerial parts being revivified by increased volume of water. In these masses small animals find shelter: *Nais*, *Anguillula*, Rotifers, and Entomostraca. The rich microflora of the Yan Yean is represented in its channel by inclusion of some of its permanent constituents, including at times plankton species which are not, or rarely, in the phytoplankton of Maroondah, O'Shannassy or Silvan.

PREVIOUS ABNORMAL INCREASES OF ALGAE.

The first superabundance of any species was that of an unknown desmid, about 40 years ago. This plant (*Micrasterias hardyi*, G. S. West) remained in excess during some weeks, then slowly diminished, and, though permanently in the plankton, has not abnormally increased since.

In 1929, soon after the infestation of the Hume reservoir on the Murray River, by *Anaboena circinalis* Rabenh., the same species appeared in the Yan Yean, and so rapidly increased that the surface water appeared pea-green, and depth samples showed a vertical distribution. After some weeks' duration, its departure was hastened by chemical treatment, following which, however, a diatom, *Melosira granulata* Ralfs, became superabundant and, after the precipitation of the Anaboena, remained for some weeks, prolonging the turbidity of the water with a milky cloudiness. This diatom diminished in numbers, but, before it became normal, another diatom, *Rhizosolenia morsa* W. and G. S. West, supervened. This species further prolonged the turbidity during some weeks and then slowly diminished. These two diatoms, though permanent constituents of the Yan Yean plankton, have rarely appeared in the channel and then only as a few scattered individuals in an abundance of other algae. That the channel was not troubled with these during their abnormal increase in the reservoir was at least partly due to the Board regulating the flow from the variable inlet valves of the outlet tower at an early date, and reserving the water during the peak period of increase.

In Maroondah in 1928, two diatoms, *Cyclotella Meneghiniana* Kütz and *C. stelligera* Cleve and Grun, increased to such an extent that chemical treatment was contemplated, but the growth naturally diminished. The only other abnormal development of algae in this reservoir was the over-production of a desmid —*Staurastrum paradoxum* Meyen, var. *longpipes*, Nordst. This was subdued with an algicide.

In the O'Shannassy there has been from its early years a disproportion of animal forms up to the appearance of crustacea and a few chlorophytes in recent years. The protozoa *Lacinularia elliptica* and *Stentor igneus* increased to the extent of macroscopic visibility, the former like innumerable sago grains, the latter like myriads of poppy seeds, and caused turbidity in the normally crystal-clear water, but with no ill effect. Diatoms were very rare in the plankton.

At no time has there been an increase of diatoms in this reservoir or its channel until the occurrence under notice. The diatoms of the channel have been chiefly those of the Ligar River, at the inlet. In Silvan reservoir, also, where there is a meagre phytoplankton, no abnormal increase of diatoms or other algae has been observed, the only untoward occurrence in its history being a plague of entomostraca (chiefly Cladocera) and a recent marginal growth of *Potamogeton ochreatus* Raoul, which attained a height of over 20 feet, in dense formation, but too recently to be a suitable home for epiphytic diatoms.

## The Infestation of the O'Shannassy Channel.

The felting of the sloping walls of the O'Shannassy-Silvan-Olinda aqueduct channel was extensive and almost continuous from the lower terminus to at least the Cement Creek crossing (where arrested accumulations were removed by the barrow load) and beyond, in diminishing quantity, but not beyond the Upper Yarra siphon which introduces water from the Silurian, a circumstance which at first seemed significant. But the felt also occurred sparsely in the Maroondah channel, in water from an exclusively dacite area.

The O'Shannassy felt is distinguished from that of the Maroondah by the predominating and, in parts, exclusive presence of a new variety of the diatom *Gomphonema oxycephalum* Cleve (8), which morphologically and in habit resembles *G. intricatum* Kütz.

## Suggestion as to Cause of the Colonization.

The foregoing description of the watersheds and channels does not indicate any topographical or geological factor as a cause of the origin of this phenomenal colonization. The only unusual meteorological occurrence which might have significance was the terrific heat wave, in the summer of 1938-9, during which temperatures in Victoria rose to 117°F., in the shade, and led to the devastating forest fires in that January. Much ash and carbon entered the forest streams, and later, during 1939-40, the soil erosion which followed the destruction of the foliage in many areas must have added a superabundance of silica to the water in those regions and so provided ample material for the construction of diatom frustules, which, according to one analysis (2)

of diatomite, amount to 40,000,000 to a cubic inch, and, to another, approx. 80 per cent. silica (3). This explanation would apply to all the channels, but does not account for the predominance in one channel of a species of *Gomphonema* which is found sparsely in the sources of all; nor the adoption of the cemented walls as a substratum. However, William Smith (1857) (3) records for *Gomphonema intricatum* Kütz " forming a velvet-like stratum on the surface of a chalk cliff . . . Sussex, August, 1890."

During a peak period a 24 hours' accumulation at the lowest screen was found to weigh approximately 2,000 pounds or 300 dry weight (avoir.). This did not include much which was removed from local screens and gratings at several points higher up; e.g., two barrow loads were removed from the highest, at the Cement Creek crossing. Thus the transportation by stream flow amounted to many tons wet weight in a season; a fresh felt forming after the natural peeling or artificial removal of the old stratum.

In the foregoing account two methods of diatomite formation are suggested—(1) The generally recognized deposition of diatoms *in situ*, in calm or nearly calm water, as indicated by the sedimentation by *Melosira granulata* and *Rhizosolenia morsa* after abnormal increase in the Yan Yean reservoir; (2) the *ex situ* deposition after transportation over considerable distances varying with stream flow, and limited only by obstacles encountered. In the latter case unimpeded fragments might reach the sea and with the disintegration of the gelatinous matrix free the frustules of the dead diatoms to be carried further afield and appear in an apparently remote marine habitat. Rare specimens of fresh water species recorded for South Polar region (4) might thus be accounted for.

But because the extensive colonization described did not occùr in the natural water courses, for lack of suitable substratum or other cause, the occurrence in the channels may be attributable to the artificial conditions. If so, it seems significant that in addition to an abundant food supply, the silica resulting from the bush fires and silt from post-fire erosion combined with the alkaline ingredient contained in the channel cement provided the necessary material for diatom-shell construction.

It is noteworthy that while the filamentous chlorophytes retained their accustomed hold on the other channels, where the diatoms while prolific were not dominant, the amount of green algae in the O'Shannassy channel was for the greater part negligible. At the same time metropolitan horse-troughs which, when constructed

with iron accommodated green algae, have been devoid of algae excepting a thin film comprising a few species and diatoms, since the construction has been of concrete and cement.

## Notes on Some of the Species.

*Gomphonema oxycephalum*, Cleve, var. *subacuta*, n. var. The type, described and figured by Cleve (8) has the upper part ot the valve within an angle, which measures 25°. In the variety the margins of the upper part of the valve are often slightly concave and there is occasionally a slight constriction at the subacute apex. The proportions of length and breadth also vary considerably, e.g., 34 $\mu$ by 6 $\mu$ and 24 $\mu$ by 5 $\mu$. The striae are more coarsely beaded; the hyaline space varies from narrow lanceolar to almost linear. The single stigma when present is not conspicuous. In general appearance the valve resembles *G. intricatum*, Kütz. In girdle view the new valves diverge about 10°.

*Melosira granulata*, Ralfs. This species is a constituent of the Yan Yean plankton, and has not been collected from O'Shannassy or Maroondah. It is normally rare in the Yan Yean channel and very rare in the felt. It increased abnormally in the Yan Yean in 1929. It is the sole species in some diatomites, viz., near Fraser Lake, Vancouver Id. B.C. (5), and Coonabarabran, New South Wales (6); it closely resembles, if not identical with, "*Melosira granulata*, Ehrenb." referred to by Card and Dun (6) as occurring in some Victorian diatomites. It is the almost exclusive species in some Canadian diatomites (5).

*Hantzschia amphioxys* (Ehrenb.) Grun. is in the highland streams and many lakes and pools in Victoria, and all the reservoirs and channels. It formed about the thousandth part (numerically) of the "Red Rain" (7) dust particles, from Central Australia, collected by me from the snow at Mt. Buffalo Chalet (4,500 feet) on July, 1935. By rough estimate about 30 lb. of the frustules of this species fell into the Yan Yean reservoir, after a dust storm of similar nature, in December, 1938. Empty frustules of any species occurring rarely in the channels without accompanying living representatives are therefore not listed (cf. 4).

*Synedra ulna* (Nitzch) Ehrenb., *S. radians*, G. S. West, *Tabellaria flocculosa* (Roth.) Kütz., *Eunotia crispula*, G. S. West, *Navicula viridis*, Kütz., *N. radiosa*, Kütz., *N. amphisboena* Bory., *N. bicapitata*, Lagerst., var., *Cocconeis placentula*, Ehrenb., *Cyclotella Meneghiniana*, Kütz., *C. stelligera*, Cleve and Grun., and *Cocconema gracile*, Ehrenb. were the most numerous species in the "mixed" parts of the felt.

## Acknowledgment.

This paper was prepared during an investigation for The Melbourne and Metropolitan Board of Works and my thanks are due to the Chairman (Mr. J. C. Jessop) for his consent to publication and to the Engineer of Water Supply (Mr. F. M. Lee) and staff for travelling facilities and other assistance. For the geological information I am indebted to the Director of the Geological Survey Vict., Mr. W. Baragwanath, and Dr. E. S. Hills.

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# ART. X.—*Eocene Deposits South-east of Princetown, Victoria.*

BY GEORGE BAKER, M.Sc.

[Read 10th December, 1942; issued separately 1st October, 1943.]


## Abstract.

Deposits of Eocene age are described from the Pebble Point district, south-east of Princetown, on the south coast of Western Victoria. The fossiliferous "Pebble Point Beds" have been established as of Eocene age from the evidence set out in the two following articles by Singleton and Teichert respectively. The Older Tertiary sediments overlying the Eocene Pebble Point Beds, are tentatively referred to the Eocene, pending the outcome of further fossil investigations. The relationship between the Jurassic rocks of this district and the Eocene rocks is described, and reference is made to Miocene beds appearing in coastal sections six miles north-west of the Eocene deposits.


## Introduction.

This paper deals with the occurrence, nature, and stratigraphical relationships of Lower Tertiary deposits exposed in coastal cliff sections between Pebble Point and the mouth of the Gellibrand River, in the parish of Latrobe, counties of Heytesbury and Polwarth (fig. 1). The basal beds of the series, consisting of ferruginous sediments, called the Pebble Point Beds, are assigned an Eocene age from independent fossil determinations made by Dr. F. A. Singleton (10), of Melbourne University, and by Dr. C. Teichert (11), of the University of Western Australia, on material collected by the author in January, 1942. Beds of clay and sandstone overlying the Pebble Point Beds, are probably also of Eocene age, but this has not as yet been conclusively established.

Pebble Point, which has a N.-S. trend, is $2\frac{1}{2}$ miles south-east of the mouth of the Gellibrand River, and approximately $3\frac{1}{4}$ miles south-east of the township of Princetown, which is situated on the south coast of Western Victoria. It is made conspicuous among a number of small headlands having similar appearances by the presence of a marked storm-wave platform cut in the Eocene rocks about 25 feet above low-tide level. Adjacent headlands have wave-cut platforms in Jurassic rocks. Pebbles of jasper, flint, rhyolite, quartzite, and agate occur on the storm-wave platform at Pebble Point, and a prominent beach sand-ridge occurs in the bay immediately to the south-east. In the Pebble Point district, the Eocene deposits rest upon eroded Jurassic rocks (Pl. X., figs. 1 and 2) on the south-western flanks of the main Jurassic area in the Otway Ranges. They extend eastwards from Pebble

Point at heights in steep cliffs which are principally beyond reach, but in a north-westerly direction, the series dips gently at 5° seawards, so that from Pebble Point to within a quarter of a mile south-east of the mouth of the Gellibrand River, occasional access can be gained to several exposures of the Lower Tertiary deposits; many parts, however, are masked by cliff débris. The approximate thickness of the Lower Tertiary series between Pebble Point and the Gellibrand River mouth is given by Wilkinson (12) as 250 feet, and of this amount, the Pebble Point Beds of Eocene age total about 50 feet. Wilkinson's value was obtained by totalling the thicknesses of the strata at three different and relatively widely spaced cliff sections; a series of beds dipping at 5° and outcropping over a distance of some 2 miles, however, would have a total thickness of over 1,000 feet.

The general geology of the Princetown area is indicated on the accompanying map, which is based upon State parish plans in the southern portion of the counties of Heytesbury and Polwarth. Few surface exposures of the Jurassic rocks occur in the area embraced by the map, and then only in cliff faces and on wave-cut platforms at headlands. They are insufficiently extensive to appear on the map (fig. 1). Coastal exposures of the Tertiary rocks are

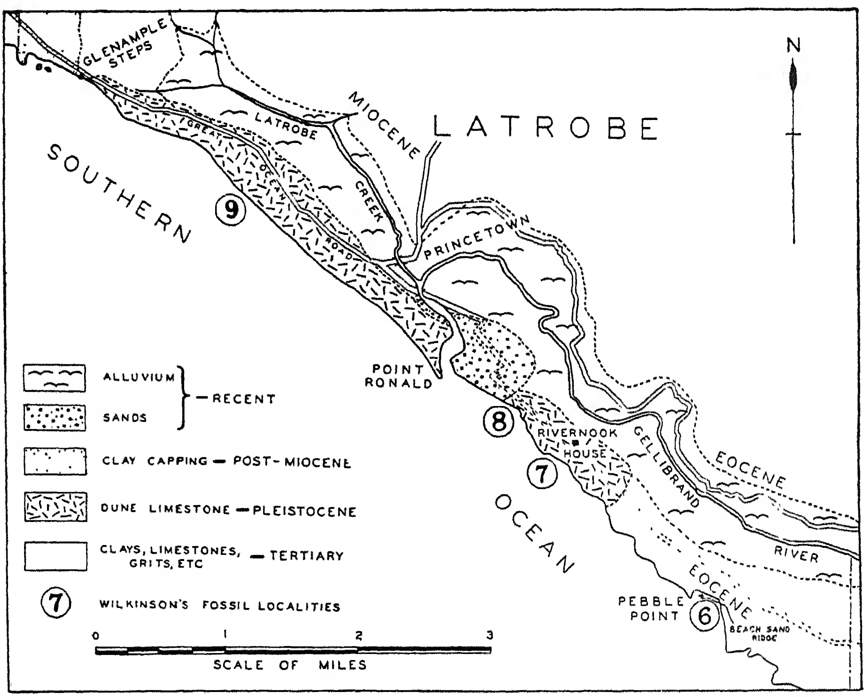


Fig. 1.—Geological map of coastline in the neighbourhood of Princetown.

principally absent from the plan, because of masking by covers of Recent sand dunes, Post-Miocene clays, and Pleistocene dune limestone.

## Previous Work.

The difficulty of access to the area and the rugged character of this little frequented portion of the Victorian coastline, are probably the principal reasons why the Pebble Point Beds and overlying deposits have received little detailed attention in the field.

The deposits were first placed on record by Wilkinson in his survey of the Cape Otway country in 1865 (12). Fossils collected during this survey, marked as coming from No. 6 locality by Wilkinson (i.e. — the Pebble Point coastal section), were subsequently determined as Nautilus, Cytheraea, and Cucullaea, and the deposits were classed in the field by Wilkinson as Miocene (12). So far, the author has been unable to locate the repository of the fossil material brought back by Wilkinson from this locality. Wilkinson's results were re-stated by Duncan in 1870 (5), in his examination of the fossil corals from Wilkinson's No. 7 locality (see fig. 1), and again by Murray in 1877 (8).

In their catalogue of described fossil species from the Cainozoic rocks of south-eastern Australia in 1903, Dennant and Kitson listed two species of *Trochocyathus* (4), *Flabellum candeanum* Edwards and Haime (4, p. 132), *Natica hamiltonensis* T. Woods (4, p. 113), *Volutilithes antiscalaris* McCoy (4, p. 100), *Vaginella eligmostoma* Tate (4, p. 94), and *Panopaea orbita* Hutton (4, p. 126) from a locality "Rivernook." This locality is marked on the State parish plan of Wangerrip as a small township a short distance inland from the coastal sections in which the Eocene rocks are exposed. The above fossil names appear in Dennant and Kitson's lists in a group classed by them as of Eocene—Oligocene age, this group also containing suites of fossils typical of Balcombian rocks.

Duncan had previously described and illustrated the fossil corals collected by Wilkinson from No. 7 locality as *Trochocyathus victoriae* (5, Pl. XIX., fig. 3) and *Trochocyathus meridionalis* (5, Pl. XIX., fig 2), while a form with a thin corallum from the same beds was described as *Cycloseris tenuis* (5, p. 301, and Pl. XX., fig. 8), and it was stated by Duncan that thin species of the Cycloserides group of corals are found in the Nummulitic beds of Southern France (5). *Cycloseris tenuis* Duncan (7, p. 362) and *Trochocyathus meridionalis* Duncan (7, p. 431), have so far only been recorded from the Older Tertiary beds south-east of the mouth of the Gellibrand River. Species of Cycloseris are regarded as primitive forms of the genus Fungia, so that *Cycloseris tenuis* is

now classed as a sub-genus of Fungia, and becomes *Fungia* (*Cycloseris*) *tenuis* Duncan sp. Species of Cycloseris are most common in Upper Cretaceous and Eocene rocks (7, p. 486).

In 1904, Dennant described *Flabellum microscriptum* sp. nov. from Wilkinson's No. 7 locality, stating that it is apparently restricted to this locality and is accompanied by *Trochocyathus victoriae*, *T. wilkinsoni*, *T. meridionalis*, and a few species of mollusca, several of which are new and peculiar to the section (3, p. 53).

In the same year, deposits referred to by Chapman as " Black beds from east of the Gellibrand River " and from which shark's teeth were described, were classed as of Balcombian (Barwonian) age by Chapman (1, p. 277), i.e., as Oligocene according to the then current ideas of the age of the Victorian Tertiary deposits. The locality from which the shark's teeth were recorded, is given as A.W.7, i.e., Wilkinson's No. 7 fossil locality. The author has so far been unable to find shark's teeth in the " Black Beds " at this locality, but numerous examples occur in a sandstone band intercalated among the dark-coloured clay deposits at No. 7 locality. The forms identified by Chapman are *Odontaspis cuspidata* Agassiz sp. (1, p. 276), a form stated to occur in the Eocene and Miocene rocks of Europe and North America, and to have a time range from Upper Cretaceous to Miocene (1, p. 290). Another form, *Oxyrhina minuta* Agassiz (1, p. 283), is said to occur in the Oligocene of New Zealand. This was subsequently described as *Isurus minutus* Agassiz sp. by Chapman (2, p. 131), because of pre-occupation of the generic name Oxyrhina by another organism.

In 1923, Pritchard stated that the coarse grits with abundant broken and imperfect fossils east of the Gellibrand River, represented a shallow water phase of the lower horizon of the Janjukian (regarded then as of Eocene age by Pritchard), and that the predominating feature of the deposits was the mixed fauna of a strong littoral type (9, p. 935).

The Eocene age of the Pebble Point Beds (i.e., at Wilkinson's No. 6 locality), has been established by the contemporaneous recognition of the nautiloids *Aturoidea distans* Teichert sp. and *Nautilus victoriana* Teichert sp. (11) and the pelecypod Lahillia (10). It is noted that Aturoidea may even be of Upper Cretaceous age (11).

Mr. W. J. Parr and Dr. M. F. Glaessner have examined the matrix in which the Eocene mollusca were found, and also the clay beds overlying them, for foraminifera. No foraminifera were found in the clay beds, but the foraminiferal content of the Pebble Point Beds is listed in the accompanying appendix.

## Occurrence, Nature, and Stratigraphical Relationships.

The bed from which the Eocene molluscs were collected is accessible in cliff sections at a point half a mile north-west of Pebble Point, at heights of some 40 to 50 feet above sea level, in a ferruginous series called the Pebble Point Beds, which are approximately 50 feet thick, and dip in a westerly direction. The contained fossils so far recognized are foraminifera, Aturoidea, Nautilus, Lahillia, Cucullaea, Nuculana, Limopsis, Eotrigonia, Dentalium, Natica, Turritella, a trochoid gasteropod, a small form of coral, large and minute fish teeth, claws of Callianassa, fish vertebrae, otoliths, whalebone fragments, and occasional fragments of fossil wood; the shelly fossils are often much broken and worn, and are embedded in a matrix of heavy grit with a ferruginous and argillaceous cement. The fossiliferous grit band overlies some 30 to 40 feet of shallow water, friable, sandy ironstones which form the base of the Eocene at this locality, and which so far have proved barren of determinable fossils, although rare, shell-like fragments can be detected.

The basal Eocene beds rest upon an erosion surface of arkoses (6) and occasional grits and mudstones of Jurassic age (Pl. X., figs. 1 and 2). Occasional grit bands, narrow veins and thicker bands of massive ironstone (limonite), occur in the Eocene sandy ironstones below the fossiliferous grit band, while narrow bands of copiapite-bearing clays and thicker bands of massive ironstone occur interstratified with the upper layers of the ferruginous beds.

Overlying the Pebble Point Beds occurs a deeper water sedimentary facies composed of dark-coloured, carbonaceous clays, which in parts contain abundant copiapite (basic iron sulphate) and structures resembling algal remains. The westerly dip of the series brings these clays down to sea level north-west of Pebble Point, and their thickness, as determined from a traverse along the coastal sections in the general direction of dip, is approximately 800 feet. Three bands of sandstone are interbedded in the carbonaceous clays, and are indicated in the coastal section (fig. 2). The nearest sandstone bed to Pebble Point, marked as "hard ferruginous sandstone" is partly ferruginous and possesses in parts rounded structures which have been produced by weathering. When broken open, some of these structures are found to be similar to "boxstones" in containing occasional casts and moulds of echinoids (Schizaster sp. indet.) and pelecypods, but the fossils are original to the deposit, and are not remanié as in true boxstones.

A second sandstone bed further to the north-west, contains numerous examples of a small form of Turritella, with corals, volutes, and Natica, while a short distance from this bed a third sandstone band 4-5 feet thick, contains abundant corals and shark's

teeth, and occasional specimens of Voluta and Dentalium. This bed is marked in fig. 2 as the "Trochocyathus-Odontaspis" band, and the locality corresponds to Wilkinson's No. 7 locality. Between, above, and below these bands of sandstone, the carbonaceous clays appear at intervals in the coastal sections, but in many places they are masked by recent talus cones built up by landslides and large fallen blocks of rock. In parts, the clays are pale yellow and grayish in colour from weathering, but when wet, the darker coloured portions are intensely black. Occasional polyzoal remains occur in clays above the Trochocyathus-Odontaspis bed, while cross sections of echinoid spines appear in a microscope section of pyritic portions of the clay from a locality about $1\frac{1}{2}$ miles north-west of Pebble Point. Portions of the clay beds are distinctly shale-like and somewhat of a bituminous character, especially above the Trochocyathus-Odontaspis bed, where crystals of gypsum and abundant pale yellow, earthy copiapite are also prominent. This carbonaceous shale is overlain by 35 feet of unfossiliferous, friable, red and yellow ferruginous sandstones which show chemical banding and contain occasional hard bands of limonite. These beds are followed by 25 feet of dark-gray clay with structures and markings resembling algal remains. The outcrops in the cliff sections at this locality, correspond in position with Wilkinson's No. 8 locality, which is about half a mile south-east of the mouth of the Gellibrand River. The beds here dip at 5° in a direction a few degrees north of west. They are overlain by sandy clays and ironstone, 8 to 10 feet of black clay, followed by further sandy clays and ironstone, which all dip north of west at 4°.

The Older Tertiary beds at the north-west end of this traverse, cease abruptly against Pleistocene dune limestone deposits a quarter to half a mile south-east of the Gellibrand River mouth. From here to the Gellibrand River, the coastal district consists of Recent dune sands (fig. 1). Two and a half to three miles north-west of the Gellibrand River mouth, clays containing a typical Balcombian (= Miocene) fauna, appear in the coastal sections, at a position corresponding with Wilkinson's No. 9 locality (fig. 1). These beds dip westerly at 5°, but the dip values diminish in amount in a westerly direction; they are stratigraphically several hundred feet above the Pebble Point Beds.

There is a considerable gap in exposures of the Tertiary rocks in the central portion of the traverse line along the dip of the Tertiary beds in the Princetown district, because the Pliocene ancestor of the Gellibrand River had carved out a valley some 4 to 5 miles wide and over 300 feet deep in the Older Tertiary deposits. This valley was subsequently infilled in successive stages with Pleistocene dune limestone, through which the present Gellibrand River has cut its course. As a consequence, no exposures of Tertiary sediments are present for a half to three-quarters of

a mile between the Eocene beds south-east of the Gellibrand River, and the Miocene beds north-west of this river mouth. Difficulty of access to portions of the coastline north-west of the river mouth and the masking of the Tertiary rocks in most places by extensive talus cones containing large fallen blocks of Pleistocene dune limestone, are also partly responsible for the lack of detailed information concerning the beds intervening between Point Ronald and the Gellibrand Clays of Miocene age south-east of Glenample Steps (fig. 1).

The traverse along the coastal cliffs from Pebble Point to the mouth of the Gellibrand River, however, has yielded more favorable results, because the Older Tertiary rocks dipping in a general westerly direction, outcrop frequently over a distance of some 2 miles. The relationships of the various members of this series, as far as can at present be ascertained, are diagrammatically represented in fig. 2. East of the area embraced by the sketch geological section, the Eocene beds can be seen in parts at heights of 50 feet or more in high, steep cliffs, where they appear to be more or less horizontal; they have been traced out beyond Pebble Point, as far east as Moonlight Head. The Eocene also appears in road cuttings along the Great Ocean-road, on the northern side of the Gellibrand River, north-east of Rivernook House.

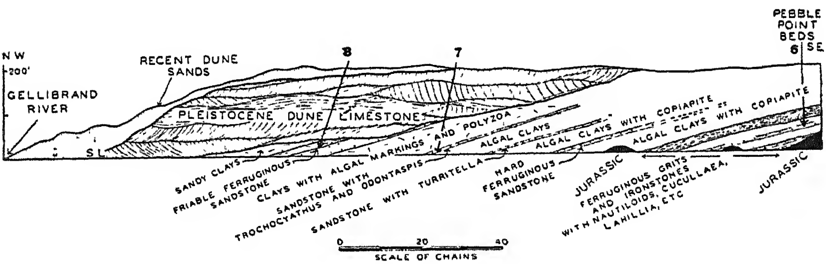


FIG. 2.—Geological sketch section along the coastal cliffs from the mouth of the Gellibrand River to Pebble Point. Dips of beds are exaggerated; the length of the section covers a distance of 2¼ miles, and the maximum height of the cliffs is about 200 feet. Numbers above the section refer to Wilkinson's localities.

## Eocene-Jurassic Relationships.

The unconformable junction between the basal beds of the Eocene and the eroded surface of the Jurassic sediments is sharply defined and relatively even in character in the cliff sections near Pebble Point. The surface of unconformity slopes down to sea-level $\frac{3}{4}$ mile north-west of Pebble Point, and becomes hidden by Recent beach sands, but a Jurassic outcrop of limited extent

appears in the coastal sections beneath Lower Tertiary clays, a short distance further to the north-west, thus indicating occasional undulations in the Jurassic sediments forming the floor of the Eocene sea. South-east of Pebble Point, the surface of unconformity rises to considerable heights in steep cliffs, and continues easterly for 4 miles to the Gable and Moonlight Head, in the parish of Wangerrip, where it has a more or less horizontal disposition.

The Eocene beds, which are conformable with one another, show slight amounts of transgressive overlap north-west of Pebble Point. Sandy ironstones, grit bands and narrow bands of massive ironstone (limonite) dipping westerly at 5° overstep one another on to the erosion surface in the Jurassic sediments, a surface which slopes at 10° in a westerly direction. On account of this overlap, it is reasonable to assume that still older members of the Eocene series may be hidden below sea level west and north-west of the Pebble Point Beds. Boring operations will be required, however, to establish this point.

On the seaward end of a wave-cut platform, which is 140 yards wide at the third point north-west of Pebble Point, massive blocks of Eocene ironstone, composed principally of limonite, rest upon the Jurassic sediments. Their disposition suggests that they have been lowered several feet on to the Jurassic platform, by the removal from below them of the more readily eroded Eocene sandy ironstones.

Occasional narrow cracks, an inch or so wide and 6 or 7 feet deep in the Jurassic rocks, have been infilled with material the same as that comprising the basal Eocene beds. Rounded pebbles of reef quartz are conspicuous in the matrix occupying these cracks.

## Age and Thickness of the Tertiary Deposits.

Of the dipping Lower Tertiary beds exposed south-east of Princetown and extending beyond Pebble Point, only the Pebble Point Beds of grits and ironstones can at present be assigned an Eocene age with any degree of certainty. Approximately 50 feet of these deposits are exposed above the surface of unconformity with Jurassic sediments, but for reasons given earlier, this fossiliferous, ferruginous series of Older Tertiary beds may have a greater thickness than is evident at the surface.

The conclusion that the deposits are of Eocene age is based upon Teichert's (11) and Singleton's (10) fossil determinations in

the group of the mollusca, and is supported by evidence from the foraminiferal content (see appended list). The thickness of the sediments overlying Pebble Point Beds and terminating against dune limestone ½ mile south-east of the mouth of the Gellibrand River has been calculated graphically at about 1,000 feet. This value is obtained from the fact that beds dipping at 5° outcrop for some 2 miles; the effects of folding and faulting have been neglected from the calculation because there is no field evidence of such earth movements in the immediate locality.

Little conclusive evidence is at present available concerning the precise age of the deposits overlying the Pebble Point Beds north-west of Pebble Point In view of Duncan's description of the coral with a thin corallum. determined as *Cycloseris tenuis,* but now classed as *Fungia (Cycloseris) tenuis* (7, p. 362), and his record of abundant thin forms of the Cycloserides group in the Eocene sediments of Southern France, it is probable that the Tertiary deposits between the Pebble Point Beds and the Pleistocene dune limestone may also be of Eocene age. Other fossil forms like Odontaspis, Isurus, Trochocyathus, Turritella, and Schizaster, collected from the various members of this series, are types which elsewhere have a time range which includes the Eocene period, although they are not necessarily characteristic of that age, *Trochocyathus victoriae* Duncan sp., for instance, occurring Recent in Port Jackson and Port Stephens, New South Wales (7, p. 436), as well as in the Older Tertiary deposits above the Eocene beds of Pebble Point.

The fixation of the upper limit of these Eocene beds must, therefore, remain in abeyance until further evidence is forthcoming from investigations of the fossil content of the beds above the Pebble Point Eocene beds. From the field evidence, the author is inclined to the belief that all of the beds south-east of the mouth of the Gellibrand River are of Eocene age. This inclination is based upon the lithological and mineralogical similarities of those carbonaceous clays which are intercalated with the upper layers of the ferruginous Pebble Point Eocene beds, and those which occur at intervals up to 2 miles north-west of Pebble Point. There are also mineralogical similarities (see Table 1) between the Eocene grit bands and the three sandstone bands containing Schizaster, Turritella, and Trochocyathus-Odontaspis, respectively (fig. 2). In addition to this, there seems to be no doubt in the field that all of the beds south-east of Princetown are conformable with one another. The Turritella band also contains a few gasteropods comparable with ones in the Pebble Point Beds.

The changes in the lithological character of the sediments from south-east to north-west, indicate a deepening of the Lower Tertiary sea in a general east to west direction, the littoral facies of undoubted Eocene age at Pebble Point, giving way in the north-west to clays containing occasional interbedded sandstones. Three miles north-west of Point Ronald, clays of Miocene age, with a typical Balcombian faunal assemblage and with similar dips to the Eocene deposits some 6 miles to the south-east, pass upwards, with diminishing dips, into Miocene limestones, calcareous clays and marls. These are more or less horizontal in the vicinity of Glenample Steps (see map, fig. 1) and extend westerly for many miles through Port Campbell, Peterborough, and Warrnambool.

Post-Miocene clays and Recent sand dunes overlie the Miocene limestones, while Pleistocene dune limestones rest unconformably upon the eroded surfaces of many members of the Lower Tertiary strata.

## Lithology and Mineralogy.

The mineral species represented in the various lithological types of the Lower Tertiary series south-east of Princetown, are listed in Table 1. Those from the Jurassic sediments of the immediate neighbourhood have been added for purposes of comparison.

### Jurassic.

The Jurassic arkose near Pebble Point is calcareous (42 per cent. acid soluble), and contains a small amount (6 per cent.) of clay constituents. The sandy fraction of the arkose is composed principally of angular quartz, with some orthoclase and oligoclase, while there are also numerous sub-angular to rounded rock fragments of microscopic size, determined as andesite, muscovite schist, chlorite schist, sandstone, quartzite, mudstone, and hornfels (6); these rock fragments and the quartz grains are all of remarkably even grade size. Plates of fresh biotite, muscovite, green and reddish-brown hornblende, chlorite, colourless, pink and brown garnet, epidote, sphene, leucoxene, hematite, tremolite, zoisite, staurolite, and apatite, are also represented in addition to the minerals listed in Table 1. Thin sections of the arkose reveal abundant calcite acting as the cementing medium and forming rims to most of the small rock fragments and mineral grains. In this feature and in several other respects, the rock resembles some examples of the Jurassic arkose from the Gippsland bores, e.g., one from a depth of 1,163 feet in bore No. 4, at Boolarra.

TABLE 1.

| | | Rock. | Locality. | Calcareous Matter. | Rounded Quartz. | Angular Quartz. | Felspar. | Mica. | Glauconite. | Collophane. | Gypsum. | Iron Ores. | Limonite. | Pyrite. | Tourmaline. | Zircon. | Rutile. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Tertiary. | 1 | Ferruginous Sandstone overlying 2 | ½ mile south-east of Point Ronald | − | + | (+) | + | + | − | − | − | + | + | − | + | + | + |
| | 2 | Carbonaceous Shale with Copiapite | ½ mile south-east of Point Ronald | tr. | (+) | + | + | + | − | + | + | − | − | + | + | + | − |
| | 3 | Sandstone with Trochocyathus and Odontaspis | 1 mile south-east of Point Ronald | + | + | (+) | + | + | + | + | − | + | + | + | − | + | + |
| | 4 | Sandstone with Turritella | 1¼ miles south-east of Point Ronald | + | − | + | + | + | − | − | − | + | + | − | + | + | − |
| | 5 | Pyritic Clay .. | 1½ miles south-east of Point Ronald | + | − | + | − | + | + | + | + | − | − | + | − | − | − |
| | 6 | Sandstone with "Box-stones" | 1¾ miles south-east of Point Ronald | + | + | (+) | + | + | + | − | − | + | + | + | + | + | − |
| | 7 | Gritty Sandy Ironstone | ¾ mile north-west of Pebble Point | + | (+) | + | + | + | + | + | − | + | + | + | + | + | − |
| Mesozoic. | 8 | Jurassic Calcareous Arkose | ¾ mile north-west of Pebble Point | + | + | (+) | + | + | − | − | − | + | + | + | + | + | + |

(+) Most common of types of quartz grains.

LOWER TERTIARY.

The sandy ironstone at the base of the Eocene series contains occasional fragments of angular quartz and felspar, and also reef quartz, Jurassic pebbles, and rare quartzite pebbles. In addition, rare rounded oolitic grains of the hydrated lime phosphate mineral collophane, pellets of glauconite and grains of black iron oxide, are set in a limonitic clayey base which forms the principal constituent of the rock.

Both the fossiliferous and the non-fossiliferous grit bands interbedded with the sandy ironstone, contain numerous large and rounded, translucent quartz grains, occasional gypsum crystals and quartzite fragments. These constituents are set in a clayey base which varies in composition from place to place. In parts, the base is ferruginous and phosphatic, and contains rare crystals of zircon, mica and tourmaline, pellets of collophane, and areas of glauconite sometimes associated with calcite. In other parts, the matrix is composed principally of calcite and limonite, while elsewhere, green and greenish-brown glauconitic mud is the most conspicuous constituent in the base of the rock. Smaller quartz grains in the grit bands are sub-angular to rounded and clear, the larger grains are frequently strained and granulated, and contain numerous strings of opaque, dust-like inclusions. Shell fragments are common in certain of the grit bands, and have in part been replaced by limonite and pyrite.

The carbonaceous clays overlying the basal ferruginous series contain pyrite in places. A section of pyritic clay, from 1½ miles south-east of Point Ronald, revealed that quartz grains present were rimmed with calcite as in the calcareous Jurassic arkose. The pyrite, which is finely granular, sometimes forms rims to, or entirely replaces the oolitic collophane grains present, but principally replaces the argillaceous material forming the bulk of the rock. The section of pyritic clay also revealed rare cross sections of echinoid spines and occasional shell fragments. Carbonaceous shale from ½ mile south-east of Point Ronald has certain characteristics akin to some oil shales. It has a sandy fraction of 7·5 per cent. and contains traces of calcareous matter. The sandy fraction is composed mainly of colourless, translucent, and milky grains of quartz. There are also flakes of mica up to 2 mm. across, and rare grains of heavy minerals (column 2, Table 1), while gypsum occurs as bladed crystals up to 3 mm. in length, and copiapite is abundantly developed along planes of fissility and as irregular clots. The cliffs here give off a sulphurous odour. A thin section of this shale indicated the presence of plant-like fragments.

Portions of the carbonaceous shale were tested for hydrocarbon compounds. After heating about 15 grams of powdered material

to a dull red heat in a hard glass test tube, abundant carbon was left behind in the residue. Volatile constituents from dry distillation consisted of water from which halite cubes crystallized on cooling, a small amount of sulphur, and a few drops of colourless liquid which had an aromatic smell and which when examined microscopically, were seen to contain pale yellowish-green globules of a liquid which persisted for several weeks The halite cubes, which were accompanied by skeleton crystals of the same material, were probably derived from salt spray driven against the cliff face from the sea. Ten to fifteen grams of the shale were powdered and treated with absolute alcohol, and the argillaceous matter filtered off. The filtrate was allowed to evaporate slowly, and at the end of this process, brownish-yellow hydrocarbon residues having wax-like properties, remained as a thin film on the bottom of the containing vessel. A positive acetone test for hydrocarbons was obtained by shaking up about 10 grams of the powdered shale with acetone and filtering. The addition of water to the clear filtrate, resulted in a milky colouration due to the formation of an emulsion. This milkiness did not develop in a control test carried out by adding water to pure acetone. Twelve grams of the powdered shale were subjected to $5\frac{1}{2}$ hours' treatment with petroleum ether in a Soxhlet extraction apparatus. The residue obtained after evaporating the petroleum ether extract contained abundant small crystals of sulphur, a whitish, wax-like substance and a pale yellowish liquid with an aromatic odour. Owing to the small amounts of the residues obtained from each of the above tests, it has not been possible so far to arrive at any definite conclusion regarding the exact character of the hydrocarbon compounds present in the carbonaceous shale.

Of the interbedded sandstones in the clay series, the bed with structures resembling boxstones consists principally of quartz, with muscovite and some felspar set in a limonitic cement containing calcium carbonate and glauconitic material (column 6, Table 1, for rarer mineral species). The calcium carbonate forms rims around some of the sedimentary grains, and has also penetrated cleavage planes in certain of the mica plates. The sandstone band with Turritella contains some altered felspar and a carbonate cement in which angular to sub-angular quartz grains are set. The sandstone with Trochocyathus and Odontaspis has a ferruginous to calcareous cement, and contains a small proportion of oligoclase and mica. Nodular areas of pyrite up to 4 mm. across are numerous in this sandstone band, and frequently entirely replace the argillaceous matrix present in parts of the rock. Some of the angular to sub-angular quartz grains contain long, slender needles and minute prisms of apatite. Rare

glauconite and oolitic pellets of brown coloured material, probably collophane representing fish pellets, &c., are also present in this sandstone.

The ferruginous sandstone overlying the copiapite-bearing, carbonaceous shale about $\frac{1}{2}$ mile south-east of Point Ronald, is friable and in parts micaceous, with angular to sub-angular quartz grains. Zircons occur both as clear, waterworn crystals and as examples with well preserved crystal faces like those in the Jurassic sediments. The other minerals present are listed in column 1, Table 1.

The minerals present in the Eocene sediments south-east of Princetown have several characteristics in common with the mineral assemblage of the Jurassic rocks upon which they rest. This is to be expected, as the basal Eocene beds are of terrigenous origin, their constituents being derived from a terrain composed of Jurassic arkose, grits, and mudstone. The pyrite in the argillaceous members of the Lower Tertiary series was probably formed by the action of $H_2S$ evolved from decomposing organic material, with the aid of bacteria, on ferrous carbonate. Weathering of the pyritic matter has brought about conversion to basic ferric sulphate, resulting in the abundant development of the mineral copiapite in parts of the deposits. Hydrocarbon compounds present in the clays originate from plant material, represented by the dark carbonaceous markings resembling algal remains. The reef quartz pebbles in the Pebble Point Beds were derived from quartz veins which traverse the Jurassic sediments in parts of the Otways.

## Summary and Conclusions.

A westerly dipping series of Lower Tertiary sediments composed of a basal ferruginous phase (called the Pebble Point Beds) overlain by a clay phase with interbedded sandstones, in coastal sections south-east of the township of Princetown, on the south coast of Western Victoria, have been assigned an Eocene age on their fossil content. They rest unconformably upon an eroded, somewhat undulating surface in Jurassic sediments, and show slight transgressive overlap. Balcombian (Miocene) beds in cliff sections some 5 or 6 miles north-west of Pebble Point, are separated from the older Tertiary sediments by a stretch of Pleistocene dune limestone which forms steep, rugged cliffs, at the base of which occasional outcrops of Tertiary rocks can be seen amongst large talus cones in those parts of the coast to which access can be gained. A considerable gap in certain parts of the Tertiary rocks between Pebble Point and Glenample Steps, has

been created by the eroded valley of the present Gellibrand River and its Pliocene ancestor, so that no definite conclusions can be made at present concerning the exact relationship between the Eocene and the Miocene deposits. The Eocene deposits have no other equivalents, as far as can be ascertained, along these parts of the Victorian coastline, being known so far only from the Pebble Point district.

Transgressive deepening of the Lower Tertiary sea from east to west is shown by the passage from basal Eocene grits and sandy ironstones, through clays and shales with interbedded sandstones, into Miocene limestones and calcareous, fossiliferous clays.

Evidence of Post-Miocene earth movements is provided by the elevation of the area of Eocene and Miocene sedimentation to its present position above sea level, but there was apparently no significant disturbance of the beds from their original disposition on deposition, the recorded dip values probably being initial dips controlled by the slope of the erosion surface of the Jurassic coastline, rather than dips resulting from tilting on elevation.

Instead of a continuous period of erosion leading to peneplanation throughout the Cretaceous and Eocene and into Oligocene times in Victoria, as originally appeared to be the case, it now transpires, with the determination of the Eocene age of the Older Tertiary deposits south-east of Princetown, that in portion of south-western Victoria at least, down-warping had set in towards the close of Cretaceous times. Erosion throughout the Cretaceous period had led to the development of a somewhat peneplaned area in the Princetown district. Increased amounts of down-warping led to the deposition of deeper water sediments in the west until, at the close of Miocene times, there was a reversal of movement, and the Eocene-Miocene rocks were elevated to form a land mass. The southern fringe of this elevated theatre of Older to Middle Tertiary sedimentation has been subjected to marine attack since Miocene times.

## Acknowledgments.

The author wishes to express his appreciation of the work of Dr. C. Teichert and Dr. F. A. Singleton, whose fossil determinations have proved the presence of Eocene deposits in Victoria, at the locality described in the text. Thanks are also due to Associate Professor E. S. Hills and Dr. M. F. Glaessner for valuable help and advice, to Mr. W. J. Parr for his examinations of the foraminiferal content of the sediments from south-east of Princetown, and to Mr. J. S. Mann for photographic preparations.

## Appendix.

THE FORAMINIFERA OF THE EOCENE BEDS AT PEBBLE POINT, PRINCETOWN.

By M. F. GLAESSNER, PH.D., AND W. J. PARR.

The presence of foraminifera in the Eocene beds of the Pebble Point area was first recognized by G. Baker, M.Sc., who subsequently asked us to examine some of the matrix adhering to the larger fossils to obtain, if possible, evidence from the microscopic fossils as to the age of the deposit. As no deposits now accepted as of undoubted Eocene age have hitherto been recorded from South-Eastern Australia, we were glad to comply with this request In addition to the material with which Mr. Baker has supplied us, we have examined some better preserved material collected by one of us (W.J.P.) from the same beds in October, 1915.

Ferruginous grits, such as occur at Pebble Point, are as a rule, unfavourable to the occurrence and recovery of foraminifera in any numbers, and it is accordingly not surprising that in the present case the microfossils are rare and of small size. After a considerable amount of searching, we have found about 28 species of foraminifera and two of ostracoda. From the examination of the material, it is, however, apparent that much better preserved specimens could be obtained by careful collecting of samples from the less ferruginous portions of the deposit.

In the meantime, the following provisional list of species is placed on record:—

*Dentalina* sp.
*Nodosaria* sp.
*Vaginulina* sp. aff. *subplumoides* Parr.
*Marginulina* aff. *costata* (Batsch).
*Marginulina* aff. *glabra* d'Orbigny.
*Lenticulina* spp.
*Planularia* sp.
*Lagena hexagona* (Will.).
*Lagena catenulata* (Will.).
*Lagena* sp.
*Globulina gibba* d'Orbigny.
*Guttulina problema* (d'Orbigny).
*Guttulina lactea* (Walker and Jacob).
*Guttulina* sp. (adherent).
*Angulogerina* aff. *elongata* (Halkyard).
*Eponides obtusus* (Burrows & Holland) var. *westraliensis* Parr.
*Gyroidina* aff. *octocamerata* Cushman & Hanna.
*Pulvinulinella* sp. nov.
*Baggatella* sp. nov.
*Ceratobulimina* spp. nov.
*Anomalina* sp. nov.
*Anomalina* cf. *glabrata* Cushman.
*Cibicides* cf. *lobatulus* (Walker and Jacob).
*Cibicides* spp.
*Globigerina* sp.

Echinoid spines, bryozoan fragments, small mollusca, ostracods and fish teeth occur also in the washings.

All foraminifera are rare except *Anomalina* sp. nov. and *Cibicides* sp., which were found in considerable numbers.

From this list, we have drawn the following conclusions:—

1. The assemblage is unlike any other hitherto recorded or known to us from Australia. The most characteristic species of the deposit appear to be new. A number of other species have a long range in time.

2. There is no disagreement between the composition of the fauna and the determination of the Eocene age of the beds at Pebble Point as based on distinctive species of mollusca.

3. Our present knowledge of the foraminiferal assemblage of the ferruginous grits from Pebble Point is insufficient for an independent determination of their age. At least four out of a total of about 28 species appear to be closely related to species not known from Tertiary deposits younger than Eocene. One of these species belongs to the genus *Baggatella* which was described recently by H. V. Howe from the Middle Eocene of Texas, U.S.A. (see Louisiana Geol. Survey, Bull. 14, p. 79). The number of specimens at present available does not enable us to reach a more definite conclusion.

4. The composition of the fauna indicates deposition in shallow and rather cool water. This opinion is based on similarities with fossil foraminiferal assemblages from sediments known to have been formed under such conditions.

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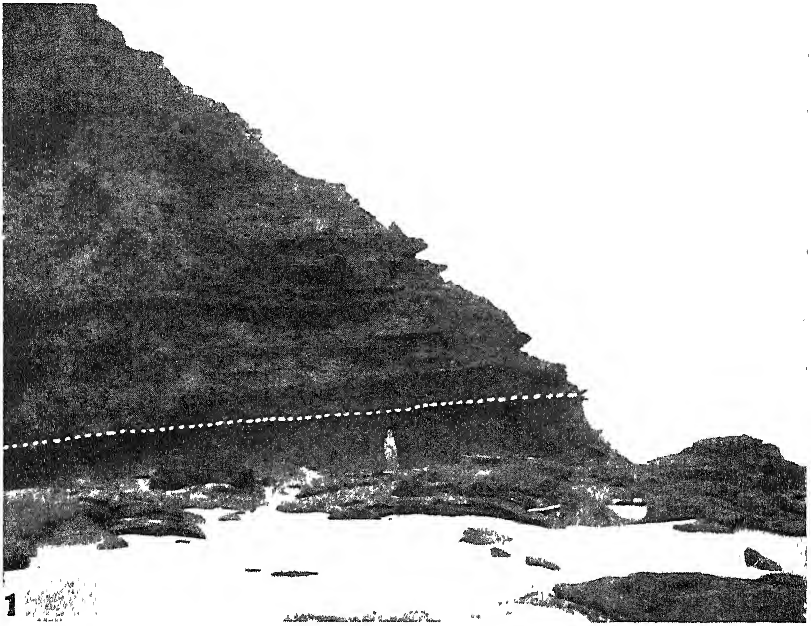
# Explanation of Plate.

## Plate X.

Fig 1.—Lower portion of the cliffs at the second point north-west of Pebble Point, showing Jurassic beds on the wave-cut platform and in the base of the cliffs. Overlying them are westerly dipping Eocene beds.

Fig. 2.—Close-up of the unconformity between Eocene and Jurassic sediments at the second point north-west of Pebble Point, showing the even character of the old erosion surface at this locality.

(Note.—The dotted line in each photograph marks the surface of unconformity between Eocene and Jurassic rocks.)



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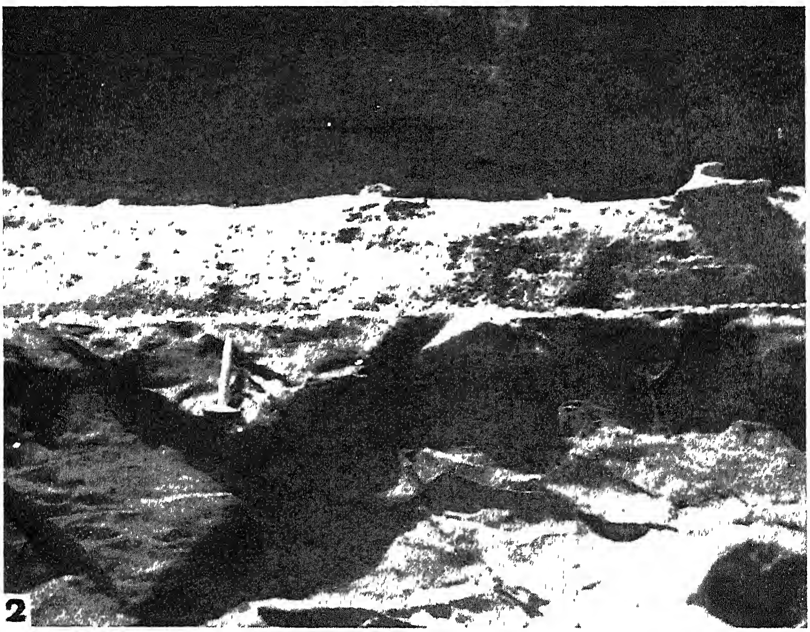

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[Page 255.]

[PROC. ROY. SOC. VICTORIA, 55 (N.S.), PT. II., 1943.]

# ART. XI.—*Eocene Nautiloids from Victoria.*

By CURT TEICHERT.

University of Western Australia, Crawley, Western Australia.
(Communicated by G. Baker, M.Sc.)

[Read 10th December, 1942; issued separately 1st October, 1943.]

## Abstract.

*Nautilus victorianus*, n.sp., and *Aturoidea distans*, n.sp., are described from Tertiary beds on the south coast of Victoria. It is concluded that the occurrence of *Aturoidea*, which has not been previously reported from Australia, indicates an Eocene age of the strata in which the nautiloids were found. This is the first suggestion of the occurrence of Eocene strata anywhere in the eastern half of the Australian continent.

At the request of Associate-Professor E. S. Hills and Mr. George Baker, of Melbourne University, I have examined the remains of a few nautiloid cephalopods, collected by Mr. Baker early in 1942 from ½ mile north-west of Pebble Point, south-east of Princetown, on the south coast of Victoria, about 20 miles north-west of Cape Otway. According to information supplied by Mr. Baker, Jurassic sandstones are in this locality overlain by a series of fossiliferous marine sediments of Tertiary age, which begins with ferruginous grits and ironstones at the base. These strata contain a small mollusc fauna which includes *Cucullaea*, *Lahillia*, *Limopsis*, *Turritella*, and *Dentalium*. The nautiloid fragments were found in a grit band in this basal series (the Pebble Point Beds) 30-40 feet above the unconformity with the Jurassic. Mr. Baker has called my attention to an early report of the occurrence of nautiloids in this place which was published by Wilkinson in 1865 and was quoted almost *verbatim* by Duncan in 1870. Wilkinson lists "*Nautilus*," together with "*Cucullaea*" and "*Cytherea*," in the uppermost beds of a series of 50 feet of thin ferruginous sandy beds which lie on top of 45 feet of greyish-brown carbonaceous sandstone showing false bedding and containing hard nodules and fragments of carbonized wood (Jurassic). The locality where fragments of carbonized wood described as "2½ miles south-east of the mouth of the Gellibrand River" and is the same as that from which Mr. Baker obtained his specimens.

Also, it must be mentioned that Chapman (1915, p. 353) listed *Aturia australis* from the "Gellibrand River (low down in the series)" and it seems possible that this determination might have

been based on fragments of *Aturoidea distans,* as described in the present paper, rather than on the true *Aturia australis* which seems to be a younger fossil.

It was found that the fragments collected by Mr. Baker belonged to four, perhaps five, different specimens of which one is here described as *Nautilus victorianus,* n. sp., whereas the other specimens belong to a new species of *Aturoidea* which is here described as *Aturoidea distans.*

The occurrence of *Aturoidea* in Victoria is of considerable interest as it seems to indicate the occurrence in that State of Tertiary strata of a greater age than any that have previously been reported from the eastern half of the Australian continent. It is one of the rarer nautiloid genera and the few species that have been assigned to it are all from strata of either Late Cretaceous or Eocene age. Apparently the genus developed out of *Hercoglossa* near the end of Cretaceous time and became extinct before the end of the Eocene, after *Aturia* had developed from it in the beginning of that period.

From the evidence furnished by this nautiloid it can be concluded, therefore, that the strata in which it was found are probably not younger than Eocene. They might even be as old as Upper Cretaceous, but since we are apparently concerned with the basal part of a continuous sequence which passes upwards into sediments of Miocene age, and since the genus *Nautilus* is not known from strata of pre-Tertiary age, an Eocene age of the nautiloid beds seems to be the most likely assumption.

Considering the fact that certain molluscs survive in Australian waters to-day which are closely related to forms that were more widespread in earlier periods, it might be argued that *Aturoidea* could have been something in the nature of an " Australian living fossil " of some period later than the Eocene. *Nautilus* itself with its present restricted range from the Java Sea to the Fiji Islands may be such a " living fossil." However, it should be borne in mind that the living species of *Nautilus* are the last descendants of a once vigorous strain which as late as the Miocene was widely distributed in various parts of the world. *Aturoidea* on the other hand was an unstable transition stage in an evolutionary lineage. Its few species are found widely apart and were never prolific in numbers of individuals.

## Palaeontological Descriptions.

### Family HERCOGLOSSIDAE.

### Genus **Aturoidea** Vredenburg.

The genus *Aturoidea* has recently been discussed in detail by Miller and Thompson (1935) to whose descriptions the reader is referred. Its species have long been confused with those of other

genera, especially *Aturia,* from which, however, they differ in important features. Miller and Thompson have drawn up the following exhaustive definition of the genus (1935, p. 566) :—

" Conch sublenticular in shape, nautiliconic in its mode of growth; all known forms large. Whorls compressed, flattened laterally, rounded ventrally, impressed dorsally. Umbilicus closed: umbilical shoulders rounded. Septa asymmetrically sigmoidal: each mature suture forms a very broad, deep, blunt ventral saddle. on either side of it a long, narrow, asymmetrical, narrowly-rounded lateral lobe; a broad, deep, broadly rounded, asymmetrical lateral saddle; a long, broad, rounded lobe with its centre near the umbilical seam; a broad, deep, broadly-rounded saddle located on the sides of the impressed zone and extending to the dorsal lobe; the dorsal lobe apparently large, more or less V-shaped, but rounded. Siphuncle subdorsal in position (that is. much nearer the dorsum than the venter, but not in contact with the dorsum); orthochoanitic in structure—segments not expanded nor contracted within the camerae but essentially cylindrical in shape; septal necks relatively long (only slightly shorter than the connecting rings)."

*Aturoidea* differs from *Aturia,* first of all in the position of the siphuncle which is not marginal as in the latter genus, but somewhat removed from the dorsum; equally important is the fact that in *Aturoidea* the septal funnels extend only half-way to the preceding septum. Finally, the septa in *Aturoidea* are farther apart than in *Aturia;* in the former genus the lateral lobe reaches approximately to the level of the crest of the lateral saddle of the preceding suture; whereas in *Aturia* the lateral lobe invariably reaches below that level.

Miller and Thompson are undoubtedly right in regarding *Aturoidea* as a connecting link between *Hercoglossa* and *Aturia.* It is a rare genus, for as Miller and Thompson have pointed out, only six or eight species have been described from North America, from England, and from India, and each species is known by one or two specimens only. Most of the species of *Aturoidea* are from Eocene strata; two species (*Nautilus serpentinus* Blanford, *N. schweinfurthi* Zittel) from the Cretaceous of India and Africa have been referred to the same genus, but these are intermediate between *Hercoglossa* and*Aturoidea* and may perhaps not be typical representatives of the latter genus.

Whether *Aturoidea* should be included in the family Hercoglossidae as Spath proposed, or rather in the Aturiidae, is an arguable, though unimportant point. The former classification suggests itself on the basis of the characteristics of the siphuncle, the latter if the state of development of the sutures is considered more important.

ATUROIDEA DISTANS, n.sp.

[Plate XI., figs. 1-4.]

This species is known from fragments of three, perhaps four, specimens which were found close together. Although it is not possible from the available material to give an exhaustive description of the species, enough of it is known to describe all its important features and to justify its description as a new species which will, it is hoped, be easily recognizable if additional specimens should be found at some future date.

The species is of fairly large dimensions. It can be estimated that the largest fragments belonged to a specimen which had a diameter of about 185 mm. at some stage before it reached maturity. Complete with living chamber the diameter of that specimen might have been anything between 250 and 300 mm.

The shell is involute; its whorls have almost straight, diverging sides and an evenly, though not very strongly rounded venter. In one rather small fragment the height of the whorl is 29 mm., its width about 24 mm., and the height of the whorl above the impressed zone is 19·5 mm. The outside of the shell is marked by weak growth-lines which are convex laterally, forming a very shallow lateral sinus, and are very strongly curved backward as they cross the venter, indicating the existence of a deep hyponomic sinus.

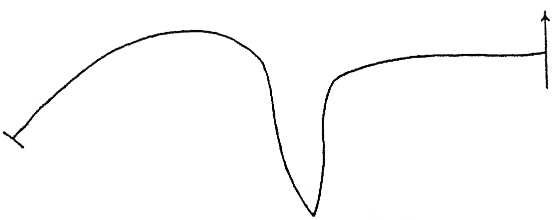

FIG. 1.—External suture of *Aturoidea distans*, n.sp. No 1860, Department of Geology, Melbourne University.

The septa are moderately convex in the median region. The siphuncle is situated a short distance from the dorsal side. In the specimen in which the height of the whorl above the impressed zone was measured as 19·5 mm., the distance of the siphuncle from the dorsal side is 1 mm. The diameter of the siphuncle at this place is 1·5 mm. In a larger fragment in which the height of the whorl above the impressed zone is 58 mm., the distance of the siphuncle from the dorsal side is 6 mm. and the diameter of the siphuncle in this place is between 5·5 and 6 mm. It seems, therefore, that the distance between the siphuncle and the dorsal side is at any stage of growth roughly equal to or only very slightly smaller than the diameter of the siphuncle at the same place. The septal necks are orthochoanitic and extend for about

half the distance between the septa. In one place where a measurement could be made the distance between two successive septa was 24 mm. and the septal necks were 12 mm. long.

The sutures are aturoid (fig. 1). The external suture consists of a strongly curved lateral saddle followed by a rather narrow, long, acute lobe which is situated well on the side of the whorl, about halfway between the umbilicus and the venter. The rest of the suture is straight as it crosses the ventrolateral and ventral parts of the conch. This part of suture remains slightly below the level of the lateral saddle. The sutures are set well apart and the lateral lobe terminates at or only very slightly below the level of the lateral saddle of the preceding suture. The internal suture forms a pair of saddles and a blunt dorsal lobe.

Occurrence.—Grit band, 30-40 feet above the unconformity between the Jurassic and the Tertiary. Second point north-west of Pebble Point, south-east of Princetown, Victoria.

Holotype.—No. 1860, Department of Geology, University ot Melbourne.

Paratypes.—Nos. 1861-1862, Department of Geology, University of Melbourne.

Remarks.—*Aturoidea distans* is easily distinguished from the few other species of the genus by the position of its lateral lobe which is unusually far away from the ventral side. From *Aturoidea spathi* Vredenburg from the Eocene Ranikot series of India it also differs conspicuously in its more broadly rounded ventral outline. A. *pilsbryi* Miller and Thompson from the Eocene of New Jersey, U.S.A., is similar in the position of the lateral lobe of the suture, but the lateral lobe is short, broad, and blunt instead of long, narrow, and acute as in *A. distans*.

Family NAUTILIDAE.

Genus **Nautilus** Linné.

Although many nautiloids of Palaeozoic and Mesozoic age have in the past been referred to the genus *Nautilus*, species that are sufficiently similar to the genotype, the living *Nautilus pompilius*, to be included in the same genus do not make their appearance before the Cainozoic. Hyatt (1897, p. 560) even hesitated to include Tertiary species into the genus and it may well be that up to the present day many species of Tertiary nautiloids are classified with *Nautilus* only because they have never been studied in sufficient detail. Although Spath has in recent years removed numerous species to a more satisfactory taxonomic position, the affinities of many others seem to require further elucidation.

While I am not in a position to be able to attempt a revision of the Tertiary species that are now commonly assigned to *Nautilus*, it is with some diffidence that I place the new species to be

described here into that genus. Its affinities will be discussed below.

NAUTILUS VICTORIANUS, n.sp.

[Plate XI., figs. 5-7.]

Only one rather fragmentary specimen is at present available which, however, permits of the observation of most of the important specific characters.

The shell which this fragment represents had a diameter of at least 47 mm., but since only part of the living chamber is preserved the actual size must have exceeded this figure. The shell is broadly discoidal, almost involute, with an umbilicus about 4 mm. wide. The whorls are strongly and evenly rounded, with a deeply impressed dorsal zone. At the base of the living chamber the whorl is about 22 mm. high, 25·5 mm. wide, and the impressed zone is about 7 mm. deep.

The surface of the shell is marked with very faint growth-lines which are slightly sinuous; they indicate the existence of a rather shallow hyponomic sinus. The septa are rather strongly convex, rising rather steeply near the ventral side. The sutures (fig. 2) form a shallow umbilical saddle, followed by a shallow lobe which

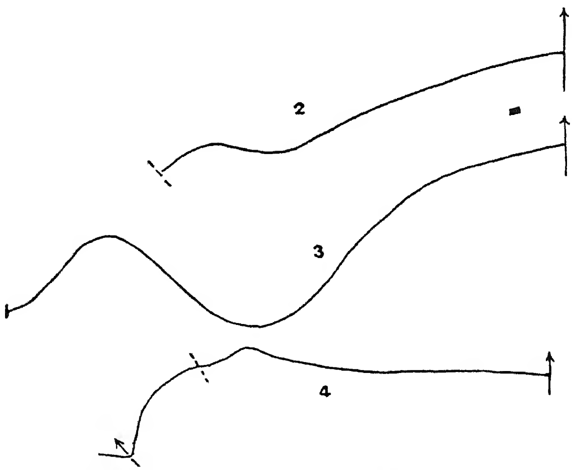


FIG. 2.—External suture of *Nautilus victorianus* n.sp., Holotype.

FIG. 3.—External suture of *Nautilus pompilius* Linné. No. 16248, Dept. of Geology, University of W.A.

FIG. 4.—Suture of *Nautilus geelongensis* Foord. No. 1863, Dept. of Geology, University of Melbourne.

is situated close to the umbilical shoulder; the sutures then rise almost straight across most of the lateral sides to form the ventral saddle. The exact course of the internal suture could not be studied, but it can be seen that a dorsal lobe is present at all stages

of growth. At a stage where the whorl is 14 mm. wide the annular lobe is about 2 mm. long; at the base of the living chamber the length of that lobe seems to have decreased to about 1 mm. The septa are comparatively closely-spaced; in the whorl preceding the last whorl the distance between them when measured near the umbilicus is between 1 and 1·5 mm. The septal necks are short and orthochoanitic.

Occurrence.—In grit band 30-40 feet above Jurassic-Tertiary unconformity. Second point north-west of Pebble Point, south-east of Princetown, Victoria.

Holotype.—No. 1864, Department of Geology, University of Melbourne.

Remarks.—The only other Victorian nautiloid with which this species can be compared is *Nautilus geelongensis* Foord (1891, p. 332). The two species resemble each other in the degree of involution of the conch; both have a very small umbilicus. Their conchs are also similar in cross-section, but the ventral side of *Nautilus geelongensis* is slightly more broadly rounded than that of *Nautilus victorianus*. The two species can be most easily distinguished by their sutures which are more strongly sinuous in *Nautilus victorianus*. The external suture of *N. geelongensis* (fig. 3) is composed of a narrow, though shallow, lobe on the umbilical wall, followed by a low saddle on the umbilical shoulder which is in turn followed by a broad and shallow lateral lobe; the venter is crossed by a broad, low saddle. The internal suture possesses an annular lobe which is present at all stages of growth. On the other hand, the more pronounced and more asymmetrical lateral lobe whose deepest point is situated closer to the umbilical shoulder are features by which *Nautilus victorianus* can be easily distinguished from *N. geelongensis*.

*Nautilus victorianus* in some respects resembles species of the genus *Eutrephoceras*. Typical species of that genus have, however, a suture which, as Davies pointed out (1935, p. 351), is situated "entirely above (in front of) the guide-line," the latter being defined as "a straight line drawn from the centre of the shell-spiral at a tangent to the suture-line in the middle of the periphery," in other words, the suture on the whole is somewhat convex. The sutures are very slightly sinuous in the umbilical region and almost straight across most of the lateral sides and across the venter. There are, however, species which are commonly referred to *Eutrephoceras* and which have more sinuous and slightly concave sutures; one of these is *Eutrephoceras bryani* Gabb from the Eocene of New Jersey, a species which has been well illustrated and described by Whitfield in 1892. The suture of this species is entirely behind the "guide-line" and its lateral lobe is more strongly developed than in normal species of *Eutrephoceras*. "*Eutrephoceras*" *bryani* is perhaps the Tertiary nautiloid in North America which resembles *Nautilus victorianus*

most, but I cannot help feeling doubtful about the systematic position of that species and wonder whether it would not be more correct to include it in the genus *Nautilus,* at least until the remaining Tertiary " Nautili " have been thoroughly revised.

For comparison with these Tertiary nautiloids an original drawing of a suture of *Nautilus pompilius* is here reproduced as fig. 4. It may be noted that this suture agrees well with the one of the same species which was figured by Reeside (1924, fig. 3), but less so with one depicted by Miller and Thompson (1933, p. 309) in which the umbilical saddle is much less prominent.

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## Explanation of Plate.

PLATE XI.

FIG. 1.—*Aturoidea distans* Teichert, n. sp. Holotype. Lateral view, Nat. size.

FIG. 2 and 3.—A chamber of another specimen of the same species (fig. 2 septal aspect, 2 ×; fig. 3 side view, nat. size).

FIG. 4.—*Aturoidea distans* Teichert, n. sp. Septal aspect of a larger fragment, nat. size.

FIG. 5–7.—*Nautilus victorianus* Teichert, n. sp. Holotype. Nat. size.

All the specimens come from a grit band 30-40 feet above the Jurassic-Tertiary unconformity, from the second point north-west of Pebble Point, south-east of Princetown, Victoria.

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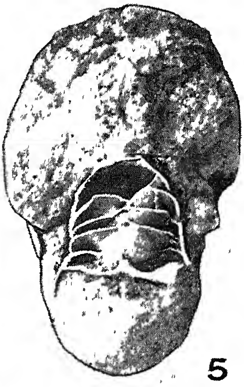

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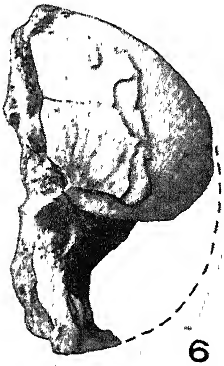

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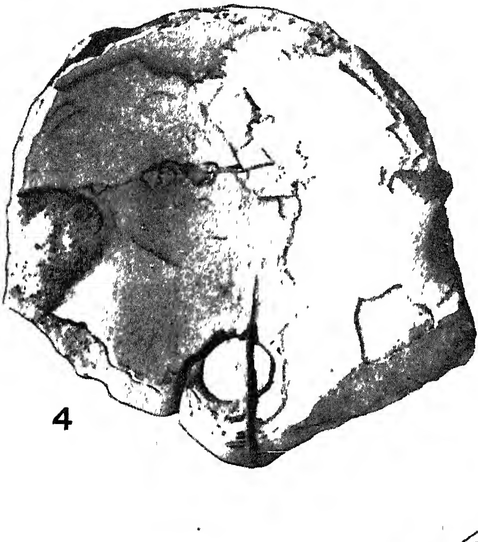

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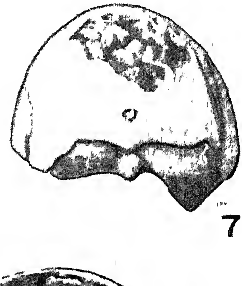

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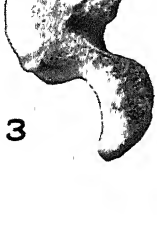

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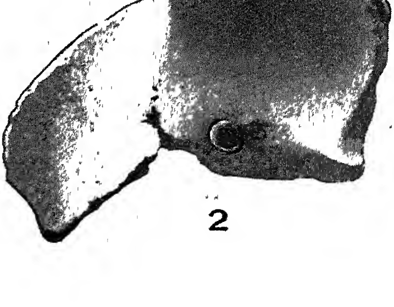

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[PROC. ROY. SOC. VICTORIA, 55 (N.S.), PT. II., 1943.]

# ART. XII.—*An Eocene Molluscan Fauna from Victoria.*

By F. A. SINGLETON, D.Sc.

[Read 10th December, 1942; issued separately 1st October, 1943.]


## Abstract.

*Lahillia-Cucullaea* fauna from ferruginous grits near Pebble Point, S.E. of Princetown, shows relationships to the Wangaloan fauna of New Zealand and more distantly to those of the Late Cretaceous and Early Tertiary of S. America and Antarctica. It is very different from known Australian faunas and is tentatively referred to the Lower Eocene or possibly Paleocene. The following are described as new species: *Nuculana paucigradata, Cucullaea* (*Cucullona*) *psephea, Lahillia australica, Dentalium* (*Fissidentalium*) *gracilicostatum.*


## Introduction.

The Older Tertiary marine deposits of Victoria were regarded by Tate and Dennant and by Hall and Pritchard as referable to the Eocene, a view still held by Dr. G. B. Pritchard. On the other hand, Professor McCoy since 1866 maintained that these beds, which for the most part are contained in the Barwonian System, were post-Eocene, a view officially adopted by the Victorian Geological Survey, and supported for the past 30 years by Chapman and by most other workers in this field, including the writer, who still believes the Barwonian deposits to be post-Eocene. Although he has recently stated (1941, p. 11) that "Paleocene to Middle Eocene horizons are as yet unknown in Australia . . .", the known Upper Eocene being confined to Western Australia, it now appears that marine deposits probably low in the Eocene, perhaps even Paleocene, are present in Victoria.

In the present paper is offered a preliminary account of the marine mollusca, other than the cephalopods, which are described by Dr. Teichert (1943), of the ferruginous grits which overlie the Jurassic strata in coastal sections near Pebble Point, about 2½ miles south-east of Princetown on the Gellibrand River. The stratigraphy is fully discussed by Mr. G. Baker (1943), to whom the writer is indebted for the opportunity to examine the fossils collected by him in January, 1942, from 30-40 feet above the Jurassic-Tertiary unconformity surface at the second point north-west of Pebble Point. Unfortunately, the very resistant matrix makes collecting difficult, and most of the present material is badly weathered and in many cases is too imperfect for specific description. Thanks are also due to Mr. W. J. Parr for placing at the writer's disposal fossils collected by him in October, 1915, from the same horizon on the south-east side of Pebble Point, and to Mr. J. S. Mann for the photographs. It is hoped that further collecting in the near future will furnish better material, and it is probable that the faunal list will be considerably increased.

## Previous Literature.

The fossiliferous beds at this locality, which is Wilkinson's No. 6, are described (1865, p. 24) by him as ". . . 50 feet of thin ferruginous sandy beds, with small rounded quartz pebbles, the uppermost beds containing fossils principally, Cuculea, Cytheroea, and Nautilus, labelled No. 6; . . ." The *Cytherea* are undoubtedly the shells herein referred to *Lahillia,* which with *Cucullaea* are the largest and commonest bivalves in these beds. More accessible than Wilkinson's report are copious extracts therefrom made by Duncan, which include (1870, p. 292) the passage above cited.

Tate and Dennant do not refer to this locality in their account (1893, p. 214) of the Tertiary beds near Princetown, though in a later paper they state (1896, p. 140): "The Otway Eocenes are certainly underlain by Mesozoic strata, but at the Gellibrand these suddenly disappear close to Pebble Point, and are not met with again to the west on either the Victorian or South Australian coast."

Pritchard (1925, p. 935) apparently referred the present beds to the Janjukian as ". . . coarse grits and conglomerates with an abundance of broken and imperfect fossils at other localities [than the Spring Creek section, i.e., type Janjukian], which clearly represent this horizon, notably east of the Gellibrand River flanking the Jurassic . . .", but no one except Wilkinson appears to have published any identifications.

## Systematic Description.

### Class PELECYPODA.

### Family NUCULANIDAE.

### Genus **Nuculana** Link, 1807.

*Nuculana* Link, Beschr. Samml. Rostock, iii., p. 155, 1807.

Genotype (by monotypy): *Arca rostrata Chemnitz* = *Mya pernula* Müller. Recent, Northern Europe. Figured by H. and A. Adams, Gen. Rec. Moll., iii., pl. 126, figs. 4*a*, 4*b*, 1858.

#### NUCULANA PAUCIGRADATA, sp. nov.

(Pl. XII., figs. 1*a*, *b*.)

Holotype.—Shell of moderate size and inflation; anterior end regularly rounded, passing evenly into the gently curved ventral margin, posterior end thin, bluntly rostrate, posterior dorsal margin long, nearly straight; umbo low, anterior; surface with distant but strongly marked growth stages, more closely spaced towards the ventral margin, otherwise apparently smooth though somewhat worn.

Hinge with chevron-shaped teeth, about nine in anterior and fifteen in posterior series, which make an angle of about 145°, as

well as three or four very minute teeth on each side of the small, deep, broadly triangular chondrophore; both series approximately linear, the anterior increasing in size, the posterior small but constant in size. Length 11 (slightly imperfect), height 6, thickness of valve 2 mm.; umbo, $4\frac{1}{2}$ mm. from anterior end.

Type Locality.—Coastal cliffs $2\frac{1}{2}$ miles south-east of Princetown, Victoria. Holotype from second point north-west of Pebble Point. Occurs also in bay south-east of this locality as well as on east side of Pebble Point.

Type Material.—Holotype (Pl. XII., fig. 1*a*, *b*) left valve, coll. and pres. G. Baker, Melb. Univ. Geol. Dept., Reg. No. 1868.

The holotype is slightly broken posteriorly, giving an appearance of truncation, but the growth lines and other specimens show the posterior end to be bluntly rostrate but not keeled. Though not uncommon, all the available specimens are more or less worn, and it is therefore with some misgiving that a specific name is given to the best of these. The length ranges from 10 to 13·5 mm., but one worn and slightly imperfect shell in the writer's possession, from the second bay north-west of Pebble Point, and apparently referable to the same species, measures 21 × 11 × 3·5 mm.

The anterior position of the umbo and lack of strong inflation of the shell seem to preclude reference to the subgenus *Jupiteria* Bellardi, which it otherwise resembles.

Of Australian Tertiary species, it distantly recalls the Kalimnan *N. praelonga* (Tate), which is at once separable by the post-median position of the umbo. The New Zealand Wangaloan *N.* (*Jupiteria*) *taioma* Finlay and Marwick (1937, p. 16, Pl. 1, figs. 1, 3, 6) shows more resemblance, but the umbo is more nearly median and the shell is apparently less produced posteriorly.

## Family CUCULLAEIDAE.

### Genus **Cucullaea** Lamarck, 1801.

*Cucullaea* Lamarck, Syst. Anim. s. Vert., p. 116, 1801.

Genotype (by monotypy): *Cucullaea auriculifera* Lamarck (= *Arca labiata* Solander = *concamera* Bruguière). Recent, Indo-Pacific. Figured by Tryon, Struct. and Syst. Conch., iii., pl. 127, fig. 74, 1884.

### Subgenus **Cucullona** Finlay and Marwick, 1937.

*Cucullona* Finlay and Marwick, N.Z. Geol. Surv. Palaeont. Bull. 15, p. 19, 1937.

Genotype (by original designation): *Cucullaea* (*Cucullona*) *inarata* Finlay and Marwick. Wangaloan (Danian), New Zealand. Figured by Finlay and Marwick, *op. cit.*, pl. 2, figs. 2-5.

CUCULLAEA (CUCULLONA) PSEPHEA, sp. nov.
(Pl. XIII., figs. 7*a*, *b*; 8*a*, *b*.)

Holotype.—A gerontic right valve. Shell moderately large, heavily built, roundly subquadrate, inequilateral, much inflated; dorsal margin weakly shouldered, anterior margin steep, passing into the gently rounded ventral margin, posterior margin oblique, weakly insinuate; posterior slope with a broad but shallow groove from the umbo to the posterior sinus; umbo anterior, prominent, strongly incurved, slightly anterior to centre of hinge-line; surface where well-preserved almost smooth, with concentric lines of growth through which are seen faint submerged radii; these are exposed in the weathered portions as strong flattened radial ribs, about seven in 10 mm. at the centre of the disc, with interspaces about half as wide as the ribs; umbonal region eroded, with about eight well marked growth stages, usually but not always with increasing interspaces which are crossed by radial riblets, about seventeen in 10 mm. at 18 mm. from the umbo; towards the ventral margin the growth-lines become undulose, directed ventrally where they cross the ribs.

Ligamental area high and long, slightly concave, with twelve or thirteen deeply incised chevrons which bear on their dorsal surfaces fine grooves subparallel to the hinge-line but tending to curl upward at the far end from the umbo; the area is 10 mm. high and deeply encroaches on the hinge teeth, of which only the anterior end of three long, striated, subparallel teeth, slightly oblique, can be seen, the posterior series being obscured by matrix; the median portion of the hinge bears irregular denticulations, about six in 4 mm. Anterior adductor scar slightly impressed, inner ventral margin of shell crenulate, rest of interior obscured by matrix. Length 60, height 50, thickness of valve 27 mm. Length anterior to hinge 3, of hinge 45, posterior to hinge 12; maximum height of hinge from ventral border 36 mm. Ratio of anterior to posterior portion of hinge 0·96.

Paratype.—An ephebic right valve. The exterior is poorly preserved and weathering has exposed the underlying radial structure. The shape in the ephebic stage is less drawn out posteriorly than in the holotype and the posterior groove is scarcely recognizable.

Ligamental area with divaricate grooving largely eroded, exposing extremely fine vertical lineations, about eight per mm.; beneath the umbo are developed coarser irregular vertical ridges which on reaching the hinge-line give place to irregular transverse taxodont teeth. Anterior and posterior teeth each four in number, the upper ones long and nearly horizontal, the lower ones much shorter and inclining downward, the sides finely transversely striate. Anterior adductor scar scalene, posterior scar subquadrate, ridged anteriorly; ventral margin internally strongly crenate, about seven in 10 mm. Length 41, height 35, thickness of valve 17 mm.

Length anterior to hinge 2, of hinge 32, posterior to hinge 7; maximum height of hinge from ventral border 27 mm. Hinge ratio 1·00.

Type Locality.—Coastal cliffs 2½ miles south-east of Princetown, Victoria. Holotype and paratype from second point north-west of Pebble Point. Occurs also in bay south-east of this locality, on the east side of Pebble Point, and in fallen blocks about ¼ mile south-east of this latter.

Type Material.—Holotype (Pl. XIII., fig. *7a, b*), Reg. No. 1869, and paratype (Pl. XIII., fig. *8a, b*), Reg. No. 1870, right valves, coll. and pres. G. Baker, in Melb. Univ. Geol. Dept.

This species is very close to *Cucullaea* (*Cucullona*) *inarata* Finlay and Marwick (1937, p. 20, Pl. 2, figs. 2-5), from which it differs chiefly in being narrower in the umbonal region and in having a much weaker posterior sinus. It is not impossible that a longer series may bridge these differences.

To the well-known Barwonian species *Cucullaea corioensis* McCoy (see Singleton, 1932, p. 300, Pl. 26, fig. 19), it bears little relation, the present species having an evenly rounded instead of oblique ventral margin, whose internal denticulation is short and marginal instead of elongate and within the margin, longitudinal hinge-teeth directed obliquely outwards and downwards instead of upwards, and external surface smooth instead of radially ribbed. Indeed, the two species are not consubgeneric, *C. corioensis* being referable to *Cucullaea, s.str.*

It is probable, however, that McCoy's locality record (Prodromus Palaeont. Vic., decade iii., p. 33, 1876) of *C. corioensis* as "Rare east of Gellibrand River (very thick variety)" is based on the present species.

### Family LIMOPSIDAE.

### Genus **Limopsis** Sassi, 1827.

*Limopsis* Sassi, Giorn. Ligustico di Scienze, etc., i., p. 476, 1827.

Genotype (by subsequent designation, Gray, Proc. Zool. Soc. Lond., pt. 15, p. 198, 1847): *Arca aurita* Brocchi. Miocene-Pliocene, Italy. Figured by Brocchi, Conchologia Fossile Subapennina, pl. 11, fig. *9a, b*, 1814.

### Limopsis, sp. nov. (?)

(Pl. XII., fig. *2a, b.*)

Shell obliquely subtrigonal, moderately convex; dorsal margin short, shouldered at either end, anterior and ventral margins regularly rounded, the latter oblique and meeting with a slight angulation the steeply sloping posterior margin; umbo minute, prominent. Surface of shell poorly preserved, but marked by strong lines of growth; near the ventro-posterior angle the crossing of these by faint radii gives rise to an obscurely tessellate ornament.

Hinge-line strongly arched, with six anterior and five posterior teeth of unequal size, the posterior series slightly uncinate, encroached upon by the prominent and high ligamental area which is longitudinally striate and divided unequally by the very large, well-developed broadly triangular ligament pit, with undulous longitudinal striae. Inner margin of shell narrowly planate, less than $\frac{1}{2}$ mm. wide. Length 10·8, height 11·3, thickness (right valve) 3·3 mm.

The above description is based on a shell (Melb. Univ. Geol. Dept., Reg. No. 1872) from the second point north-west of Pebble Point, collected by Mr. G. Baker. Although the poor preservation of the exterior of this and of the other specimens available makes it undesirable to attach a specific name, there is little doubt that it is distinct from other Australian Tertiary species of *Limopsis.*

The nearest species in point of age, the Janjukian *Limopsis chapmani* Singleton, is much less oblique at corresponding sizes and is ovate in outline instead of almost subquadrate, the ligament pit is much smaller, and the planate inner margin is nearly three times as wide as in the present species.

### Family CARDIIDAE.

### Subfamily LAHILLIINAE Finlay and Marwick, 1937.

### Genus **Lahillia** Cossmann, 1899.

*Amathusia* Philippi, Tert. und Quart. Verst. Chiles, p. 135, 1887. Not *Amathusia* Fabricius, Mag. f. Insektenk. (Illiger), vi., p 279 (Lepidoptera), 1807, nor *Amathusia* Rafinesque, Analyse de la Nature, p. 119 (Neuroptera), 8vo, Palermo, 1815.

*Theringia* Cossmann, nom. nov., Revue critique de Paléozool, iii. (1), p. 45, Jan., 1899, as *lapsus* for *Iheringia*, corrected, *op. cit.*, iii. (2), p. 90, Apr. 1899. Not *Iheringia* Lahille, Revista Mus. La Plata, viii., p. 437 (Echinoidea), 1898.

*Lahillia* Cossmann, nom, mut., *op. cit.*, iii. (3), p. 134, July, 1899.

Genotype (for both *Amathusia* Philippi and *Lahillia*, by subsequent designation, Finlay and Marwick, N.Z. Geol. Surv. Palaeont. Bull. 15, p. 31, 1937); *Amathusia angulata* Philippi. Tertiary, Chile. Figured by Wilckens, N. Jahrb. f. Min. Geol. u. Pal., Beilage Bd., xviii., pl. 20, fig. 4, 1904 (exterior only); Ortmann, Rept. Princeton Univ. Exped. Patagonia, iv. (2), pl. 27, figs. 4*a*, *b*, 1902 (hinge).

It might be argued that *Theringia* Cossmann, though stated by him to be a typographical error, is nevertheless a valid substitute name for *Amathusia* Philippi. Strangely enough, the same misprint *Theringia* occurs, as a nomen nudum, in Bull. Soc. Géol. France [3], xxvi (6), p. 586, March, 1899, in a note on Lahille's paper. Since *Theringia* and *Iheringia* have each been used in two senses, it seems desirable to accept Cossmann's second substitute name *Lahillia*, which is well established in literature.

LAHILLIA AUSTRALICA, sp. nov.
(Pl. XII., figs. 3-5.)

Holotype.—Left valve, shell large, thin, roundly ovate, moderately inflated, anterior slope gentle, posterior slope steep; anterior dorsal margin straight, descending and passing smoothly into the evenly rounded anterior margin, posterior dorsal and posterior margins evenly but more gently curved than anterior end, meeting the broadly convex ventral margin without angulation; umbo prominent, broad, sub-median; lunule scarcely defined. Surface with low, broad, concentric folds, about 2 mm. wide with 5 mm. interspaces on the ventral slope, and somewhat irregular growth-lines, best developed on the posterior slope, where they are sharply raised and crowded.

Interior largely obscured by matrix, but hinge characters as far as seen closely agreeing with paratype. Length 76, height 73, thickness of valve 26 mm.

Paratypes.—Exterior poorly preserved but agreeing in sculpture with holotype. Right valve slightly more elongate; left valve markedly so, being more produced posteriorly; lunule in left valve excavate, bounded by a rounded ridge.

Hinge-plate thick; cardinal and posterior lateral teeth well developed, anterior laterals absent. Right hinge with small, blunt anterior cardinal, gently sloping on its dorsal and anterior surfaces and distant from the raised lunular margin, steeply sloping posteriorly to a large, deep, broadly triangular pit, inclined slightly forward. Posterior cardinal very strong and prominent, sub-triangular, arising nearly opposite umbo but directed obliquely backward and drawn up to a blunt peg-like apex, somewhat recurved upwards; anterior surface descending steeply to the triangular socket of the left anterior cardinal, posterior slope steep, descending to surface of nymph, which is high and broad. A low narrow ridge runs down nearly vertically immediately behind the umbo and the posterior cardinal; it does not reach the latter but dies out about a quarterway across the hinge-plate. Behind this ridge is a shallow depression, but there is no definite pit for the left posterior cardinal. Posterior lateral very strong, elongate, blunt, above which is a deep, wide pit separating it from the raised posterior edge of the nymph. Hinge-plate anterior to cardinal teeth with a linear shallow depression below and parallel to the lunular margin, otherwise somewhat steeply sloping towards the ventral margin of the hinge-line, which is strongly sinuate, with downward curves opposite the posterior cardinal and posterior lateral.

Left hinge with strong, high anterior cardinal directed anteriorly at about 15° from the vertical, separated from the arched and raised lunular margin; the upper surface of the tooth recurved and somewhat rounded, its lower surface triangularly bevelled and

buttressed anteriorly by a ridge which forms the lower margin of the broad triangular pit for reception of the right anterior cardinal. Left posterior cardinal narrow, low, directed posteriorly at about 25° from the vertical, decreasing in width and height until it dies out at the ventral margin of the hinge-plate. Surface of nymph slightly excavate, its upper edge bounded by a deep ligamental groove. Posterior lateral strong, but less heavy and elongate than that of right valve, and separated from the post-dorsal margin by a narrow elongate pit. Ventral margin of hinge-line only weakly sinuate below cardinal and posterior lateral teeth.

Adductor scars strong, deeply sunk, especially on inner sides, posterior the larger, situate high up near dorsal margin of shell. Pallial line obscure. Inner margin of shell smooth. Length 77, height 71, thickness of right valve 26 mm.; 78, 71, 26 mm. (left valve).

Type Locality.—Coastal cliffs 2½ miles south-east of Princetown, Victoria. Holotype from second point north-west of Pebble Point; paratypes from east side of Pebble Point. It is also found between these localities.

Type Material.—Holotype (Pl. XII., fig. 5) left valve, coll. and pres. G. Baker, Melb. Univ. Geol. Dept., Reg. No. 1865; paratypes (Pl. XII., figs, 3, 4) right and left valves, coll. and pres. W. J. Parr, Reg. Nos. 1866-7.

The present species is less closely related in dentition to the genotype of *Lahillia,* as figured by Ortmann (1902, Pl. 26, figs. 9*a*, *b*), than to *Lahillia neozelanica* Marshall and Murdoch, the type of the subgenus *Lahilleona* Finlay and Marwick (1937, p. 31). From the hinge of the New Zealand shell as figured by these authors (1937, Pl. 4, figs. 8, 9) that of the Australian species differs in the more robust right anterior lateral, the slightly backward instead of forward sloping right posterior lateral, and the better developed left posterior cardinal. In other characters, the correspondence is close. *L. australica* has, however, a higher anterior dorsal margin and thus an oval outline instead of the subtrigonal shape of topotypes of *L. neozelanica* from Wangaloa, and may therein more closely resemble the high-shouldered Boulder Hill form of *L. neozelanica* reported by Finlay and Marwick.

Unfortunately, in none of the Australian shells is the pallial line clearly seen, but in one broken example it appears to descend steeply and obliquely forward from near the inner angle of the posterior scar without a sinus such as characterizes *Lahilleona.* For this reason and because of the backward slope of the posterior cardinal, a difference already noted by Wilckens (1924, p. 540) for the S. Patagonian *L. luisa* (Wilckens) of Upper Senonian age, the present species is not referred to *Lahilleona* although it otherwise appears so close to *L. neozelanica.*

*Lahillia luisa*, as figured by Wilckens (1910, Pl. 3, figs. 4-7, 11) from Graham Land, Antarctica, is a more elongate shell, more produced anteriorly and truncate posteriorly. In the left hinge the cardinals are more divergent and the ventral margin of the hinge is strongly instead of weakly sinuate; in the right valve this margin shows a very strong angulation posterior to the cardinals, while the posterior lateral tooth is at a greater angle to the horizontal than in *L. australica.*

Of the Tertiary *Lahillia larseni* (Sharman and Newton) (1900, pp. 59, 60, and Pl., as *Cyprina Larseni*; Wilckens, 1911, pp. 13, 14, Pl. 1, fig. 12) from Seymour Island, off Graham Land, the hinge-teeth and pallial line are unknown; it is, however, a more elongate shell than *L. australica.*

## Class SCAPHOPODA.

### Family DENTALIIDAE.

### Genus **Dentalium** Linné, 1758.

*Dentalium* Linné, Syst. Nat., ed. 10, p. 785, 1758.

Genotype (by subsequent designation, Montfort, Conch. Syst., ii., p. 23, 1810): *Dentalium elephantinum* Linné. Recent, East Indies (Amboyna) and Philippine Islands. Figured by Pilsbry and Sharp, Tryon's Man Conch, [1] xvii, pl. 1, figs. 1-7, 1897.

### Subgenus **Fissidentalium** Fischer, 1885.

*Fissidentalium* Fischer, Man. Conchyl., p. 894, 1885.

Subgenotype (by monotypy, as section): *Dentalium ergasticum* Fischer. Recent, Gulf of Gascony and Atlantic Ocean. Figured by Pilsbry and Sharp, *loc cit.*, pl. 15, figs. 35-36, 1897.

### Dentalium (Fissidentalium) gracilicostatum, sp. nov.

(Pl. XII., figs. 6*a*, *b*; Pl. XIII., figs. 9*a*, *b*.)

Holotype.—Shell moderately large, solid, tapering fairly rapidly, moderately curved, dorso-ventrally compressed, slightly elliptical in cross-section, wall thick, apex wanting.

Surface with fine longitudinal ribs, about 57 in number; at the narrower end the ribs are unequal in size, rather high, narrow, rounded above, and parted by furrows which are wider than the ribs; anteriorly the ribs become broader and flattened, so that the interspaces are relatively much narrower and almost linear. The longitudinal sculpture is crossed by faint lines of growth, more marked towards the larger end, where they indicate that the aperture was decidedly oblique, and by somewhat irregular growth stages, about eight in number. Length (imperfect) 22; transverse diameter of apertural end, 5·5; dorso-ventral diameter, 5; thickness of shell, 0·8; diameter of posterior end, 3·7 (transverse), 3·2 mm. (dorso-ventral). Change in direction of axis in 2 cm., about 8°.

Type locality.—Coastal cliffs $2\frac{1}{2}$ miles south-east of Princetown, Victoria. Holotype from bay between first and second points north-west of Pebble Point. Occurs also at Pebble Point and at the second point north-west of it.

Type Material.—Holotype (Pl. XII., fig. 6*a*, *b*; Pl. XIII., fig. 9*a*, *b*), coll. and pres. G. Baker, Melb. Univ. Geol, Dept., Reg. No. 1871.

Although the apical characters are unknown, the specimens available being very imperfect, the size and solidity of the shell and its numerous riblets justify its reference to *Fissidentalium*. The fineness of the ribbing and the thickness of the shell wall readily distinguish it from other Australian Tertiary species.

## Age of the Fauna.

The paucity and imperfect preservation of the shelly fauna of the Pebble Point beds make correlation difficult, but it is at once evident that the occurrence of *Lahillia* sharply differentiates it from the known Australian faunas and links it rather with those of South America, Antarctica, and New Zealand.

In Chile, *Lahillia* ranges from the Upper Cretaceous (Senonian) Quiquirina beds to the Miocene Navidad beds, while in South Patagonia and in Graham Land the range is approximately the same. In no case is the relation to *Lahillia australica* particularly close. In New Zealand, Finlay and Marwick (1937, pp. 10, 13, 31-3) discuss the late Cretaceous records of *Lahillia* and refer its highest occurrence, as *Lahillia* (*Lahilleona*) *neozelanica*, in the Wangaloan, to the Danian. *Lahillia australica*, as noted under that species, appears closer to *L. neozelanica* than to the South American and Antarctic forms, were it not that the New Zealand shell is sinupalliate. Such a character implies so marked a distinction that it is unfortunate the Australian material does not permit a decision as between *Lahilleona* and *Lahillia, s. str.* The backward slope ventrally of the posterior cardinal tooth is a character shared with the Upper Senonian *Lahillia luisa* and on the whole *Lahillia australica* appears related more closely to the late Cretaceous than to the Tertiary species.

While *Cucullaea, sensu lato,* ranges from the Mesozoic to the present, the subgenus *Cucullona* has hitherto been reported only from the Wangaloan. Indeed, the Australian *C. psephea* is so close to the Wangaloan *C. inarata* as to suggest approximate identity of age.

Of the remainder, *Nuculana paucigradata* and the *Limopsis* afford little definite evidence as to age. The former only distantly resembles the Wangaloan *N. taioma,* while the latter is very different from the Wangaloa species.

*Dentalium* (*Fissidentalium*) *gracilicostatum* is also quite unrelated to the Wangaloan scaphopods: *Fissidentalium* did not appear, so far as the writer knows, before the Eocene.

The conclusions to be drawn from this survey are not very definite. The complete specific, and in part generic or subgeneric distinction from the Australian Janjukian faunas, even when the latter are of comparable shallow water facies, as at Table Cape, Tasmania, suggests a considerable time difference, so that it is unlikely that the Pebble Point fauna is younger than Eocene. The earliest occurrence of the *Lahillia-Cucullaea* association is in the Senonian of South America and Antarctica, where it is associated with ammonoids; in New Zealand, it is found without ammonoids on a higher horizon, the Wangaloan, correlated by Finlay and Marwick with the Danian, but not in the Bortonian (? Middle Eocene); and it persists into the Tertiary of South America and Antarctica.

The Pebble Point fauna, therefore, probably falls within the range from Danian to Lower Eocene, a conclusion supported by the occurrence (Teichert, 1943) in it of the Nautiloid genus *Aturoidea*, which elsewhere has this range. A correlation with the Wangaloan is suggested by the occurrence in both of *Cucullona*, but the writer is not fully convinced that the Wangaloan is Danian rather than Paleocene, and, moreover, the Wangaloan fauna contains a Cretaceous element as yet unknown in the fauna here described. The occurrence in the Pebble Point beds of *Fissidentalium* points also to an Eocene age, so that they may tentatively be referred to the Lower Eocene, with a possibility that they may be as old as Paleocene.

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## Explanation of Plates.

### Plate XII.

Fig. 1a, b.—*Nuculana paucigradata*, sp. nov. Holotype. × 2.

Fig. 2a, b.—*Limopsis*, sp. × 2.

Fig. 3.—*Lahillia australica*, sp. nov. Paratype, right hinge, nat. size.

Fig. 4.—*Lahillia australica*, sp. nov. Paratype, left hinge, nat. size.

Fig. 5.—*Lahillia australica*, sp. nov. Holotype, nat. size.

Fig. 6a, b—*Dentalium (Fissidentalium) gracilicostatum*, sp. nov. Holotype, *a*, lateral aspect; *b*, dorsal aspect, × 2.

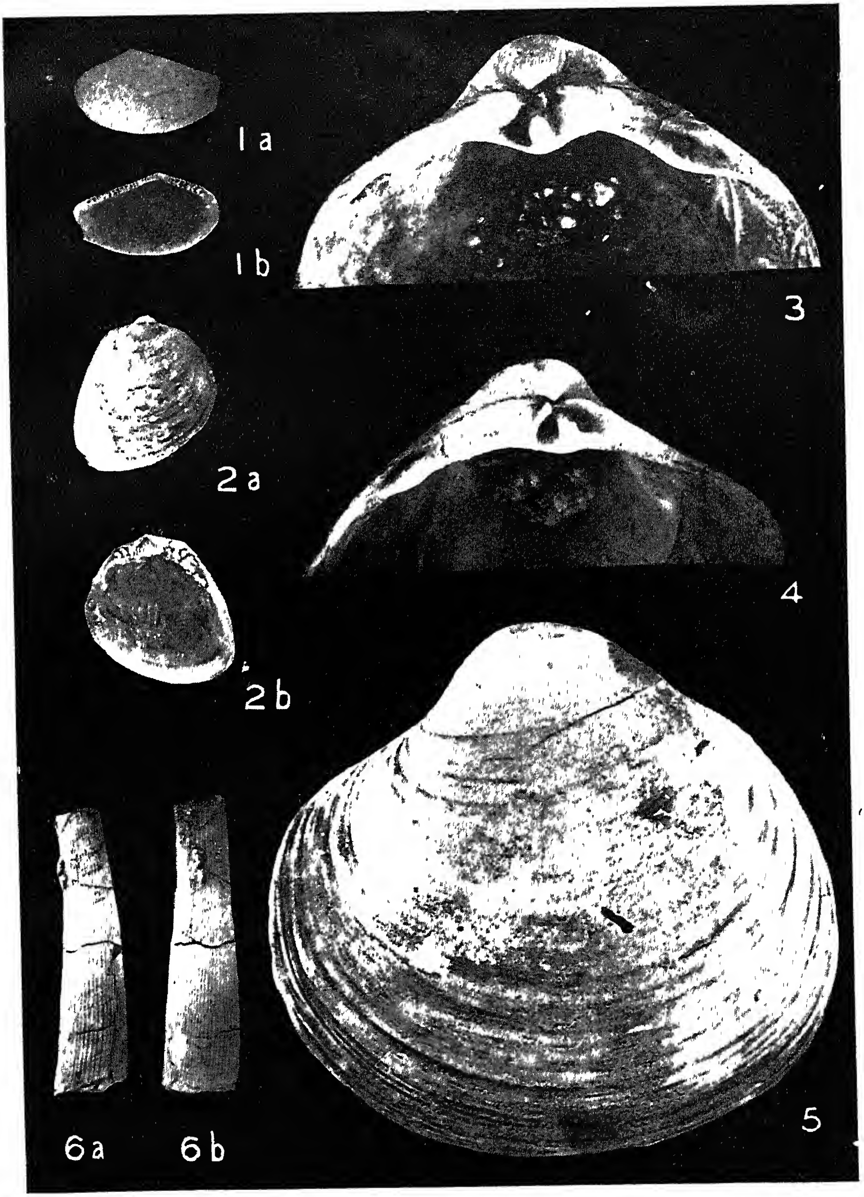
### Plate XIII.

Fig. 7a, b.—*Cucullaea (Cucullona) psephea*, sp. nov. Holotype, nat. size.

Fig. 8a, b.—*Cucullaea (Cucullona) psephea*, sp. nov. Paratype, nat. size.

Fig. 9a, b.—*Dentalium (Fissidentalium) gracilicostatum*, sp. nov. Holotype, a posterior portion of Fig. 6b. × 6; *b*, ornament. × 12.

Note:—Owing to discolouration by ferruginous stains, the shells were coated with ammonium chloride before being photographed.

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**Victorian Eocene Mollusca.**



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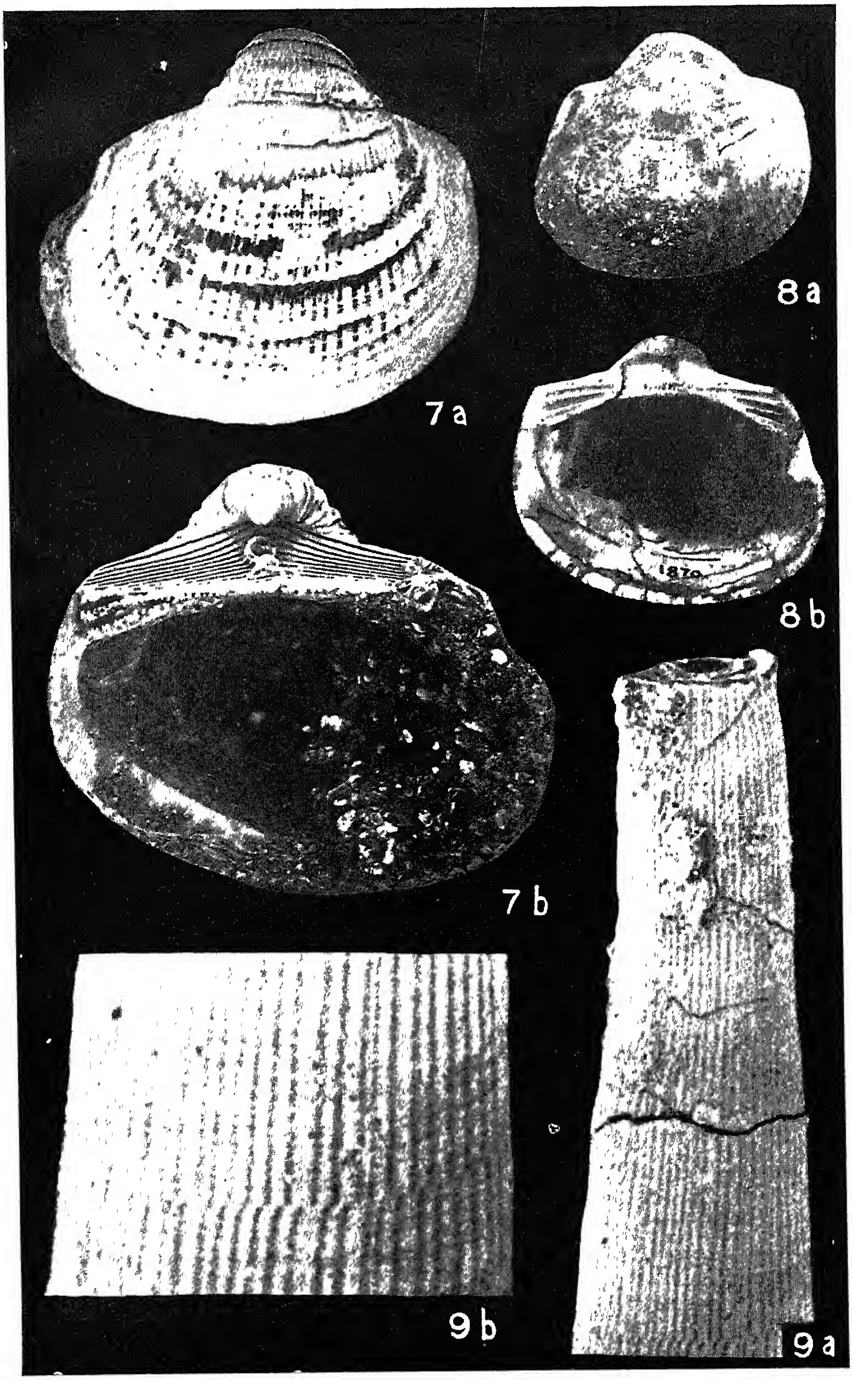


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| Kernot, Prof. W. N., B.C.E., M. Mech. E., M. Inst. C.E., 10 Princes-avenue, East Caulfield, S.E.5 | 1906 |
| Kershaw, J. A., F.R.E.S., 11 Wrexham-road, Prahran, S 1 .. | 1900 |
| Mahony, D. J., M.Sc., National Museum, Russell-street, Melbourne, C.1 | 1904 |
| Osborne, Emeritus Prof. W. A., M.B., B.Ch., D.Sc., "Lowestoft," Warrandyte, Victoria | 1910 |
| Pratt, Ambrose, 507 Riversdale-road, Surrey Hills, E.10 . .. | 1918 |
| Selby, G. W., Glenbrook-avenue, Malvern, S.E.5 .. .. .. | 1889 |
| Skeats, Emeritus Prof. E. W., D Sc., A.R.C.Sc., F.G.S., 27 Kensington-road South Yarra, S.E.1. | 1905 |
| Sweet, Georgina, D.Sc., "Queongo," 64 Mont Albert-road, Canterbury, E.7 | 1906 |

### ORDINARY MEMBERS.

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| Balfour, Lewis J., B.A., M.B., B.S., 62 Hopetoun-road, Toorak, S.E.2 | 1892 |
| Baragwanath, W., Geological Survey Department, Treasury Gardens, East Melbourne, C.2 | 1922 |
| Barker, Prof. A. F., M.Sc., 10 Pasadena Mansions, St. Kilda-road, S.C.2. | 1940 |
| Barrett, A. O., 1 Queen-street, Melbourne, C.1 .. .. .. | 1908 |
| Barrett, Sir J. W., K.B.E., C.M.G., M.D., M.S., 105 Collins-street, Melbourne, C.1 | 1910 |
| Bull, L. B., D.V.Sc., Animal Health Research Laboratory, Parkville, N.2. | 1939 |
| Casey, Major Dermot A., M.C., c/o Melbourne Club, Collins-street, Melbourne, C.1 | 1932 |
| Cherry, Prof. T. M., B.A., Ph.D., University, Carlton, N.3 .. | 1930 |

Clark, A. M., M.Sc., 9 Grattan-street, Hawthorn, E.2 .. .. 1940
Clark, G. Lindesay, M.C., B.Sc., M.M.E., c/o Gold Mines of Australia Ltd., P.O. Box 856K, Melbourne, C.1 1931
Cudmore, F. A., 12 Valley View-road, East Malvern, S.E.6 .. 1920
Davis, Captain John King, 35 Wills-street, Melbourne, C.1 .. .. 1920
Dyason, E. C., B.Sc., B.M.E., 92 Queen-street, Melbourne, C.1 .. 1913
Edwards, A. B., D.Sc., Ph.D., D.I.C., Geology School, University, Carlton, N.3 1930
Esserman, N. A., B.Sc., A.Inst.P., National Standards Laboratory, University Grounds, Sydney 1923
Gepp, Sir Herbert W., Box 1643, P.O., Melbourne .. .. 1926
Gill, Rev. E. D., B.A., B.D., 26 Winifred-street, Essendon, W.5 .. 1938
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Hills, Assoc. Prof. E. S., D.Sc., Ph.D., Geology School, University, Carlton, N.3 1928
Hordern, A., 233 Domain-road, South Yarra, S.E.1 .. .. 1940
Jack, R. Lockhart, B.E., D.Sc., F.G.S., c/o Broken Hill Pty Ltd., 422 Little Collins-street, Melbourne, C.1 1931
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Jutson, J. T., D.Sc., LL.B., "Darlington," 9 Ivanhoe-parade, Ivanhoe, N.21 1902
Keble, R. A., National Museum, Melbourne, C.1 .. .. .. 1911
Lang, P. S., B.Agr.Sc., School of Agriculture, University, N.3 .. 1938
Leeper, G. W., M.Sc., Chemistry School, University, Carlton, N.3 .. 1931
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Miller, Leo F., "Moonga," Power-avenue, Malvern, S.E.4 .. 1920
Millikan, C. R., M.Agr.Sc., Plant Research Laboratory, Swan-street, Burnley, E.1 1941
Morrison, P. Crosbie, M.Sc., 44-74 Flinders-street, C.1 .. .. 1938
Nicholas, Geo. R., 48 Lansell-road, Toorak, S.E.2 .. .. 1934
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Pittman, H. A. J., B.A., B.Sc.Agr. (Hons.), Dip.Ed., Plant Research Laboratory, Swan-street, Burnley, E.1 1942
Priestley, R. E., M.A., D.Sc., University, Birmingham .. .. 1935
Quayle, E. T., B.A., 27 Collins-street, Essendon, W.5 .. .. 1920
Reid, J. S., 498 Punt-road, South Yarra, S.E.1 .. .. .. 1924
Richardson, A. E. V., M.A., D.Sc., C.M.G., Council for Scientific and Industrial Research, 314 Albert-street, East Melbourne, C.2 1938
Rigg, Gilbert, 20 Finch-street, Malvern, S.E.5 .. .. .. 1931

Rivett, Sir David, M.A., D.Sc.. Council for Scientific and Industrial Research, 314 Albert-street, East Melbourne, C.2 1911
Rogers, J. Stanley, B.A., M.Sc., University, Carlton, N.3 .. .. 1924
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Withers, R. B., M.Sc., Dip. Ed. Technical School, Brunswick, N.10 1926
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Wright, Prof. R. D., D Sc, M B, M.S, F R.A C S, F R A.C.P., University, Carlton, N.3 1941

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Blackburn, Maurice, M.Sc., Fisheries Section, C.S I.R., Cronulla, N.S.W. 1936
Caddy, Dr. Arnold, "Chandpara," Tylden, Vic. .. .. .. 1924
Caldwell, J. J., Geological Survey Office, Bendigo, Vic. .. .. 1930
Cox, H. M. S., Wombat Park, Daylesford .. .. .. 1931
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Currie, Mrs. Ian, Seven Oaks, Euroa .. .. .. .. 1941
Glaessner, M. F., Ph.D., c/o Mines Department, Melbourne .. 1939
Harris, W. J, B.A., D.Sc., High School, Echuca, Vic. . .. 1914
Hope, G. B., B.M.E., "Carrical," Hermitage-road, Newtown, Geelong, Vic. 1918
Lawrence, A. O., B.Sc., Dip. For., 509 Ligar-street, Ballarat .. 1931
Mackenzie, H P., Engr. Commr, R.N. (Ret.), Trawalla, Vic. .. 1924
Mann, S. F., Caramut, Vic. .. .. .. .. .. 1922
Quayle, D. S., 33 Gent-street, Ballarat .. .. .. .. 1939
Thomas, D. E., c/o Geological Survey, Mines Dept., Hobart .. 1929
Trebilcock, Captain R. E., M C., Wellington-street, Kerang, Vic. .. 1921
White, R. A., B.Sc, School of Mines, Bendigo, Vic. .. .. 1918

## Associates.

Aitken, Miss Y., M.Agr.Sc., School of Agriculture, University, Carlton, N.3 1936
Alderman, A. R., M.Sc., Ph.D., F.G.S., Box 4331, G.P.O., Melbourne, C.1 1942
Bage, Miss F., M.Sc., O.B E., Women's College, Kangaroo Point, Brisbane, Qld. 1906
Baker, G., M.Sc., Geology Department, University, N.3. .. .. 1935
Brazenor, C. W., National Museum, Russell-street, Melbourne, C.1 1931

Broadhurst, E., M.Sc., 457 St. Kilda-road, Melbourne, S.C.2 .. 1930
Buchanan, Gwynneth, D.Sc., University, Carlton, N.3 .. .. 1921
Butcher, A. D., M.Sc., Fisheries & Game Dept., 605 Flinders-street, C.1 1936
Butler, L. S. G., No. 3 Los Angeles Court, St. Kilda, S.2 .. .. 1929
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| Jona, J. Leon, M.D., M.S., D.Sc., Lister House, 61 Collins-street, Melbourne, C.1 | 1914 |
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| Prentice, H. J., B.Sc., 218 Esplanade West, Port Melbourne, S.C.7 | 1936 |
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| Rayment, Tarlton, Bath-street, Sandringham, S.8 .. .. .. | 1929 |
| Richardson, Sidney C., "Fernlea," Upalong-road, Mount Dandenong | 1923 |
| Sayce, E L., B.Sc., A.Inst.P., Research Laboratories, Maribyrnong, W.3 | 1924 |
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| Shaw, Dr. C. Gordon, 57 Clendon-road, Toorak, S.E.2 .. .. | 1931 |
| Sherrard, Mrs. H. M., M.Sc., 43 Robertson-road, Centennial Park, N.S.W. | 1918 |
| Stach, L. W., M.Sc., 250 Riversdale-road, Hawthorn, E.3 .. | 1932 |
| Thomas, L. A., B.Sc., c/o Council for Scientific and Industrial Research, Stanthorpe, Queensland | 1930 |

| | |
|---|---|
| Traill, J. C., B.A., B.C.E., 630 St. Kilda-road, Melbourne, S.C.3 .. | 1903 |
| Trudinger, W., 27 Gerald-street, Murrumbeena, S.E.9 .. .. | 1918 |
| Tubb, J. A., M.Sc., Fisheries Section, C.S.I.R., Cronulla, N.S.W. . | 1936 |
| Vasey, A. J., B.Agr.Sc. Animal Health Laboratory, Parkville, N.3 | 1937 |
| Vasey, G. H., B.C.E., University, Carlton, N.3 .. .. .. | 1936 |
| Wade, G. C., B.Agr.Sc., Plant Research Laboratory, Swan-street, Burnley, E.1 | 1941 |
| Whincup, Mrs. Sylvia, B.Sc., Geology Department, University, N.3 | 1942 |
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| Wilson, Major H. W., O.B.E., M.C., C. de G., M.Sc., 630 Inkerman-road, Caulfield, S.E.7 | 1923 |
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| Woodburn, Mrs. Fenton, 21 Bayview-crescent, Black Rock, S.9 .. | 1930 |
| Wunderly, J., D.D.Sc. (Melb.), 7 Victoria-road, Camberwell, E.6 .. | 1937 |

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# Art. I.—*Kaolinised Granodiorite in the Bulla-Broadmeadows Area.*

By A. J. GASKIN, M.Sc.

[Read 13th May, 1943; issued separately 1st August, 1944.]


## Abstract.

The evidence provided by the chemical and mineralogical composition and the field occurrence of the kaolinised granodiorite is examined with a view to determining the most probable mode of origin of the deposits. The evidence now available, though inconclusive in itself, suggests that the kaolinising agencies might have been associated with the extrusion of the Tertiary basalts.


## Introduction.

The occurrence of kaolinised granodiorite in the Bulla-Broadmeadows area has been noted by Dunn (1899), Armitage (1911), Stillwell (1911), and James (1920). The nature of the process which has given rise to irregular patches of kaolinised granodiorite, scattered over the surface of an otherwise normal intrusion, has been the subject of much discussion. Dunn and Armitage believe that the kaolin was produced by the action of meteoric waters, whilst Stillwell and James suggest that pneumatolysis was more probably responsible for the kaolinisation.

The most complete review of the evidence relating to the cause of kaolinisation was given by James (1920), who concluded that microscopical examination of the kaolinised material gave no definite evidence in favour of either of the above theories, but that " the field evidence, while producing little positive evidence in support of pneumatolysis, strongly discounts the meteoric theory."

The present paper contains the results of an examination of the physico-chemical characteristics of the kaolinised felspar and the associated minerals in an attempt to deduce the nature of the conditions under which kaolinisation took place. The evidence relating to the field occurrence of the altered material is then re-examined in order to decide the most probable way in which these conditions were brought about.

## Field Occurrence of the Deposits.

GRANODIORITE.

The granodiorite outcrops in the Bulla district are so closely related, both chemically and mineralogically, to the neighbouring outcrops in the Broadmeadows district, that there is no reason to doubt the suggestion that they are both portions of the same igneous intrusion. Although chemical analyses quoted by James (1920) suggest that the granodiorite at Bulla contains slightly less potash and slightly more lime than the corresponding rock from Broadmeadows, and the orthoclase-plagioclase ratio of the latter caused Stillwell (1911) to term it an adamellite, the distinction has no significance as far as the present investigation is concerned.

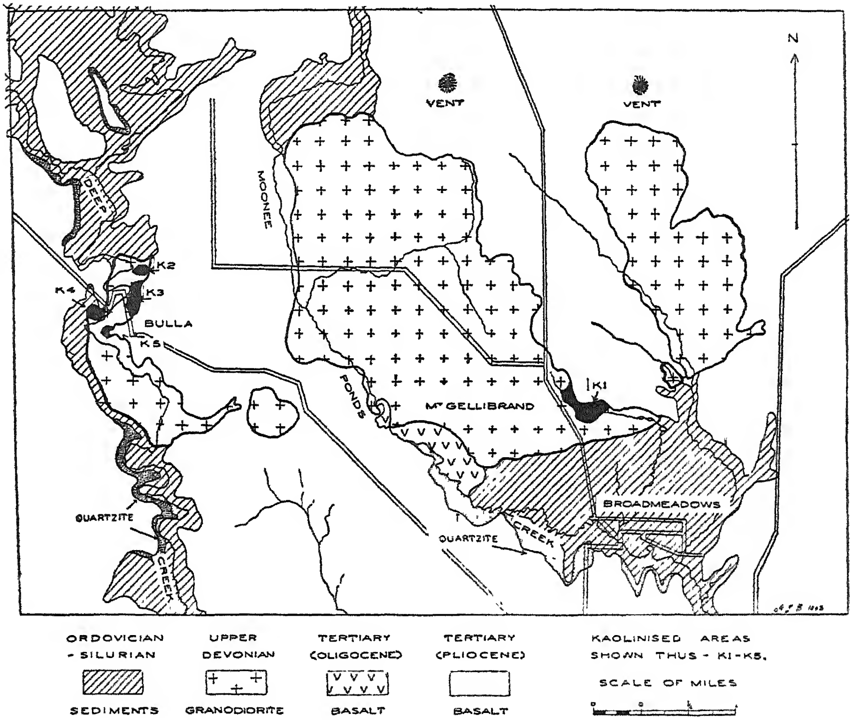
The geological map appended to this paper (p. 3) is based on a combination of the maps of Stillwell (1911) and James (1920), together with portions of Quarter Sheets 2 and 7 of the Geological Survey. It shows the Bulla-Broadmeadows intrusion as a stock-like body, elliptical in plan, extending about seven miles along its E.-W. axis, and about four miles along its N.-S. axis. On its northern, western, and southern boundaries, it junctions with contact metamorphosed Silurian and Ordovician sediments. Because of its analogies to similar granodiorites in Central Victoria, it is probable that the intrusion is of Upper Devonian age. The intrusion was exposed by erosion prior to the Tertiary, portion of it being covered during that period by fluviatile conglomerates, which were later covered by the basalts of the Older Volcanic series. Extensive lacustrine deposits separate portions of the Older Volcanic from the Newer Volcanic flows, a series of which have been extruded from vents near the western and northern boundaries of the area shown in the map (p. 3). The basalts of the newer Volcanic series extend across the granodiorite in two parallel tongue-like flows, leaving the central and two outer portions of the intrusion exposed as inliers standing up above the basalt flood. Post-Newer Volcanic erosion has exposed much of the western portion of the granodiorite that was originally covered with basalt.

KAOLINISED GRANODIORITE.

At Bulla, where the basalt has been removed by erosion, extensive outcrops of kaolinised granodiorite have been exposed, but no kaolinised granodiorite occurs above the surface level of the basalt.

It is not possible to trace definite connexions between the various kaolin outcrops here, since they are now separated by the valley of Deep Creek. There is a possibility that most of the present outcrops were originally joined to form a single large body of kaolinised material. However, the ridge of fresh granodiorite separating the kaolinised outcrops west of Deep Creek

(K4), from those to the east of the stream (K2, K3, K5) rises almost to the level of the basalt, so that any former connection between these two main kaolin deposits must have been but a shallow layer at the surface.




Geological Sketch Map of the Bulla-Broadmeadows Area.

Kaolinised granodiorite occurs at a high level (420 ft.) and at a low level (300 ft.), the maximum depth of kaolinisation in any single outcrop being about 90 ft., judging from the cliff exposures (K2) immediately to the north of the main bridge over Deep Creek. At this place, the kaolinised material at the bridge level is fresher in appearance than that at higher levels in the cliff, being blue-grey in colour, and containing numerous flakes of unaltered biotite and fragments of cloudy felspar. Completely kaolinised granodiorite can be observed to overlie fresher material in the valley wall of Deep Creek, where fresh granodiorite is

exposed at a spot 20 ft. below and 20 ft. to the west of, the floor of the kaolin quarry (K5) on the side road to Bulla School. About 60 feet of kaolinised granodiorite overlies fresh granodiorite in the gully (K4) across the creek from the school

The upper surface of the kaolinised granodiorite is extremely well defined in some instances, the clean upper surface of the kaolin being in direct contact with the lower surface of the basalt. In other instances, 10 to 20 ft. of ferruginous grit and sand overlie the kaolinised material and are overlain by basalt. The latter has given rise to some silicification of the grits, converting them in part into quartzites In the main road cutting at Bulla (near K3), the grits and sands contain small boulders of kaolinised and partially silicified granodiorite up to 6 inches in length, and markedly angular in form, showing facets, edges, and blunt points.

At Broadmeadows, a recently developed quarry (K1) in kaolinised granodiorite on the east flank of Mount Gellibrand was extending rapidly to the west and south when operations were suspended because of the war. The lateral extent of the kaolinised material is as yet unknown because of the thick soil covering to the east, west and south of the quarry The kaolin is covered by basalt to the north and north-east, but can be traced round the boundary of the flow for several hundred feet to the north-west. The floor of the quarry is in kaolinised granodiorite at a level 20 ft. below the surface. Although the rock has been kaolinised for a distance of several hundred feet to the south of the basalt contact, the upper surface of the kaolinised material is, as at Bulla, below the upper surface of the basalt. In the main face of the quarry, the kaolinised material is divided into two parts by a vertical dyke-like body, containing only fine-grained quartz and kaolinite. The material is distinct from the surrounding kaolinised granodiorite, its appearance suggesting kaolinised quartz porphyry. The " dyke," which appears to strike approximately north-south, is from 10 to 20 ft. in thickness, and is exposed in the floor of the quarry for a distance of 40 ft to the north, where it disappears under the basalt. Any southerly continuation is obscured by a thick soil layer. The contact between the dyke and the granodiorite is sharply defined, indicating that the intrusion of the dyke took place subsequent to the consolidation of the granodiorite and before the kaolinisation of the latter.

### Extrusives.

In the area, the basaltic flows of the Newer Volcanic series can be divided into two groups, which James (1920) has termed the Upper and Lower series. At one place on the Sunbury-road, at the top of the rise from Bulla township, kaolinised granodiorite

is covered by a thin flow of basalt belonging to the Lower Series. The flow is honeycombed with vesicles up to an inch in length, indicating the presence of an abundance of gaseous material at the time of extrusion. A thicker flow of dense massive basalt, belonging to the Upper series, overlies this thin vesicular flow. Because of the absence of distinguishing characteristics which could be used to classify the various flows, there is as yet no consistent evidence connecting the occurrence of kaolinised granodiorite with any particular flow or group of flows.

## Composition of the Deposits.

### Clay Minerals.

In the hand specimen and under the microscope, there are no significant differences to be found in the appearance of samples of kaolinised granodiorite from any of the Bulla-Broadmeadows outcrops, with the sole exception of the material from the kaolinised " dyke " in the Broadmeadows Quarry, the fine-grained character of which suggests that quartz porphyry rather than granodiorite was the parent rock.

Thin sections show the normal kaolinised granodiorite to be composed of large (5-10 mm.) quartz grains, set in a matrix of kaolinite, bleached biotite, and muscovite, with minor amounts of zircon, calcite, and apatite.

The clay mineral, which is the most abundant mineral in the sections, occurs in irregular patches composed of book-like aggregates of minute flakes. These aggregates are elongated in the direction of the normal to the plane of basal cleavage, several of the more elongated " books " showing the sinuous curves of the characteristic " worm-like " aggregates of kaolinite described by Ross and Kerr (1930). Where the individual flakes are large enough to be observed, they show straight extinction, low birefringence, and a mean refractive index of 1.566. Indistinct interference figures suggest an optic angle (2V) of about 20°, the character being negative.

Since the minute grain size of the clay fraction militated against exact identification by optical means alone, the physical properties of the material were further investigated, as the exact identification of the predominant clay mineral has an important bearing on the problem of the nature of the conditions prevailing during the alteration of the granodiorite. The further properties on which the identification of the clay minerals was based were:

(i) chemical composition
(ii) dehydration curve
(iii) adsorptive properties
(iv) crystal structure.

(i) Chemical Analysis of the Clay Fraction.

Table II., Column IV., shows an analysis of the clay separated by sedimentation from the Bulla kaolinised granodiorite. The analysis suggests that a mineral of the kaolinite group forms the greater part of the material. The considerable amount of water expelled below 110°C. suggests that an appreciable amount of halloysite was present, as Ross and Kerr (1934) have shown that minerals of the halloysite type are capable of holding somewhat more water by "mechanical" bonds than are minerals of the kaolinite type. The proportion of halloysite to kaolinite indicated by the analysis (and in the dehydration curve) is, however, greater than that which prevailed in the samples as they were originally collected. This is a result of the sedimentation treatment necessary to remove quartz and mica, a portion of the kaolinitic clay fraction being separated in flake-aggregates which settle rapidly and are discarded with the fine quartz fraction.

(ii) Dehydration of the Clay Fraction.

The various clay minerals of the kaolinite group lose their combined water at different and characteristic temperatures (Ross and Kerr, 1930). A check may thus be made on an identification by plotting the dehydration curve of the clay mineral. The clay fraction concerned in the present investigation showed a small, continuous loss of water between 110° and 450° (see fig. 1). At the latter temperature, a sudden loss in weight occurred, as is exhibited by kaolinite, little further loss occurred between 500° and 800°, so that it may be assumed that dickite and nacrite were not present in appreciable quantities.

(iii) Adsorptive Properties of the Clay Fraction.

After separation from the altered granodiorite by sedimentation, the clay-fraction was treated with methylene blue to determine its adsorptive properties, and with malachite green to determine its base exchange capacity The procedures are similar to those described by Faust (1940).

*Methylene Blue.*—About 0.1 gram of the clay fraction was agitated in a 1 per cent. aqueous solution of the dye, until no more dye was removed from the solution, which was then filtered off, the stained mineral being air-dried and examined under the microscope. All of the kaolin in the altered rock from Bulla and Broadmeadows was found to adsorb the dye strongly, the individual flakes being stained an intensely deep blue. When partially stained, the flakes retained a slight transparency and were feebly pleochroic from light to dark blue. The blue-grey polarisation colours of the flakes (viewed normal to the basal plane) appeared to be raised on staining to second order reds, as

described by Bosazza (1940). The colour appears to be distinct from the reddish reflection tint which the dye imparts to the surfaces of the flakes

The above staining treatment established the clay mineral as kaolinite, as distinct from dickite and nacrite, which do not adsorb the dye to any appreciable extent Montmorillonite and its analogues are not distinguished from kaolinite by this test, but show characteristic behaviour when treated with malachite green.

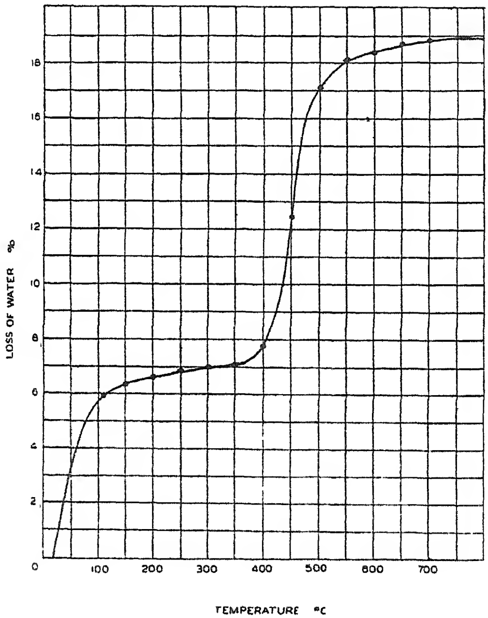



Fig. 1—Dehydration Curve of Kaolin Mineral obtained from Kaolinised Granodiorite, Bulla (K 3).

*Malachite Green.*—The clay fraction was suspended in boiling dilute HCl for two hours, after which the acid was removed by filtration, and the residue washed free from acid. The washed mineral was then treated with a 1 per cent. neutral aqueous solution of malachite green, filtered, and allowed to dry. During such an acid treatment, clay minerals with replaceable cations form hydrogen substitution products which, when treated with the dye, inhibit the dissociation of the adsorbed malachite green. The particles are thus stained the yellow colour characteristic of the undissociated dye molecules. The clay mineral from the Bulla-Broadmeadows deposits showed behaviour characteristic of

the minerals of the kaolin group, i.e., the flakes were stained a deep blue-green by surface adsorption, with no indications of any base-exchange capacity.

It was found possible to stain bleached biotite to some extent with both the above stains, thereby providing a useful test for distinguishing this mineral from muscovite, which generally does not adsorb any appreciable quantity of the dye. Flakes of biotite showing a marginal rim of the bleached material are common in the less severely altered portions of the granodiorite, and these, when treated with the dyes, adsorb the dye in their bleached portions, the inner area of fresh biotite remaining unstained.

(iv.) X-Ray Examination of the Clay Fraction.

X-ray "powder" photographs of the clay-fraction from the Bulla-Broadmeadows kaolin outcrops indicated that the clay-mineral is kaolinite, thus confirming the identification made by the other methods described in this section.

*Procedure.*—The clay-fraction, separated by sedimentation, was air-dried at 20°C., mixed into a thick paste with collodion, and extruded from a fine-bore glass tube to form a rod about 1 mm. in diameter. When dry, the rod was mounted in a circular camera, 57.3 mm. in diameter, and exposed to filtered copper radiation for four hours. Line spacings were measured on the resultant film and are necessarily approximate because of the diffuse nature of the lines. The pattern agrees fairly well with that given by Kerr (1930) for kaolinite.

Table I.

| Arc in m.m. | Intensity. | Lattice Spacings A.U. |
|---|---|---|
| 9·9 | 10 | 4·464 |
| 10·8 | 10 | 4·194 |
| 12·4 | 6 | 3·614 |
| 13·1 | 5 | 3·424 |
| 17·9 | 9 | 2·512 |
| 19·3 | 10 | 2·344 |
| 19·5 | 4 | 2·305 |
| 22·6 | 4 | 2·005 |
| 27·6 | 6 | 1·666 |
| 31·3 | 7 | 1·487 |
| 35·8 | 5 | 1·347 |
| 38·7 | 4 | 1·233 |

The line corresponding to the 1.487 spacing was relatively stronger and more diffuse than the same line in the photographs of kaolinite reproduced by Ross and Kerr (1930), suggesting that a certain amount of halloysite was present in the kaolinite from Bulla. Photographs of halloysite are characterised by a strong, diffuse line (1.510 AU) which almost coincides with the kaolinite 1.487 AU line. (Ross and Kerr, 1934).

## Associated Minerals.

Quartz occurs in rounded grains, showing no signs of alteration from the original form of the mineral in the fresh granodiorite. A considerable amount of fine-grained secondary quartz is present in most kaolinised specimens, especially those which were obtained from outcrops immediately below the silicified sands and gravels which cover portion of the granodiorite.

Muscovite is present in both the kaolinised granodiorite and in the fresh rock. There is only a small quantity of sericite present, most of the particles being well-developed flakes from 0.1-1 mm. across.

*Bleached Biotite.*—Much of the biotite of the original granodiorite has undergone extensive decomposition into a colourless material which resembles muscovite, but may be distinguished from that mineral by optical and chemical means. Thus, the bleached biotite has a smaller optic angle (2V about 10°-20°) than muscovite (2V from 30°-40°). Flakes of the bleached biotite frequently retain some of the pleochroism of the fresh mineral, whilst the completely colourless material may be readily distinguished from muscovite by its capacity for the adsorption of dyes from dilute solution. It is possible that this adsorptive effect is partly due to the presence of finely dispersed kaolinite which would probably be produced to some extent during the bleaching of the biotite.

Since little information was available regarding the composition of bleached biotite, an attempt was made to determine its probable composition by spectrographically analysing an aggregate of flakes of the mineral selected under the microscope. The spectrograms obtained, when compared with those of normal biotite, showed that the bleached material contained much less iron and magnesium, and rather less manganese, titanium and nickel than normal biotite.

*Accessory Minerals.*—Heavy mineral concentrates from the kaolinised material contained zircon (common), garnet (rare) and limonite (rare). Baker (1942) recorded zircon and garnet in the fresh granodiorite.

## Chemical Analysis of the Kaolinised Granodiorite.

Table II. shows comparison analyses of fresh and kaolinised granodiorite from Mt. Gellibrand (Broadmeadows) and an analysis of the clay mineral (kaolinite with some halloysite), together with an analysis of the parent rock from which the clay has been derived. From columns I. and II., it can be seen that kaolinisation has been accompanied by a considerable loss of MgO, CaO, $Na_2O$ and $K_2O$, the deficiency being made up by a corresponding increase in the content of chemically held water. The

amount of iron which has been removed is not great, but oxidation of ferrous iron to the ferric state has occurred to a large extent. The titanium content of the kaolinised material has increased by about 80 per cent., while most of the manganese has been

TABLE II.

| — | I. | II | III. | IV. |
|---|---|---|---|---|
| $SiO_2$ | 67·75 | 67·38 | 66·13 | 45·02 |
| $Al_2O_3$ | 16·11 | 16·21 | 16·83 | 35·85 |
| $Fe_2O_3$ | ·50 | 3·45 | 1·11 | ·99 |
| FeO | 4·00 | ·48 | 4·17 | ·24 |
| MgO.. | ·79 | ·29 | 1·83 | ·65 |
| CaO.. | 2·68 | ·71 | 3·26 | 1·76 |
| $Na_2O$ | 2·60 | ·86 | 2·25 | ·03 |
| $K_2O$ | 3·42 | 2·35 | 3·14 | ·25 |
| $H_2O+110°$ | ·20 | 5·72 | ·23 | 8·90 |
| $H_2O-110°$ | ·96 | ·88 | 1·68 | 5·90 |
| $CO_2$ | Nil | Tr. | Tr. | Tr. |
| $TiO_2$. | ·85 | 1·40 | Tr | ·57 |
| $P_2O_5$ | ·09 | ·07 | Tr | Tr. |
| MnO | Tr. | ·02 | ·07 | Tr. |
| Cl . | Tr. | Tr. | Tr | Tr. |
| | 99·95 | 99·82 | 100·70 | 100·16 |

I.—Adamellite, Mt Gellibrand. (Analyst. H. C. Richards) (James, 1920)
II.—Kaolinised Granodiorite, Mt. Gellibrand. (Analyst: A. J Gaskin)
III.—Granodiorite, Bulla. (Analyst· F Watson) (James, 1920).
IV.—Clay-fraction, Bulla (Analyst A J. Gaskin).

removed from the altered rock. All of the above changes in composition are typical of the processes of weathering and leaching by meteoric waters, the kaolinisation of the granodiorite having rendered the granodiorite porous and particularly subject to supergene attack. The removal of such components as magnesia, lime, soda, potash, and, to some extent, iron, in the form of their soluble bicarbonates and chlorides, is to be expected in the case of an igneous rock, such as the Bulla-Broadmeadows granodiorite, which has been mechanically broken up by decomposition and exposed to atmospheric attack. The fixation of titanium in the form of the insoluble hydrated titanium oxide known as leucoxene (Edwards, 1942) is a process common in such residual products of supergene weathering as clays, bauxites and laterites. Adsorption of hydrated titanium compounds, or lattice replacement of aluminium by titanium, might account for the considerable amount of $TiO_2$ (0.57 per cent.), associated with the fine clay which was separated from the kaolinised granodiorite by sedimentation (Table II., Column IV.). Since there is no visible rutile or ilmenite present in the kaolinised rock, the 80 per cent. increase in its $TiO_2$ content must be ascribed to the presence of secondary compounds, such as leucoxene, derived from ilmenite in the original rock by the action of the solutions engaged in leaching the kaolinised masses, or from titanium-bearing solutions accompanying the extrusion of the basalts.

## SPECTROGRAPHIC ANALYSIS OF KAOLINISED GRANODIORITE.

Pneumatolytic action is generally accompanied by the introduction of various metallic elements into the rock body which is being attacked, though it is theoretically possible for pure water vapour, associated with mineral acids, to cause "pneumatolytic" alteration of certain minerals. It has been suggested (James, 1920), that the kaolinisation of the Bulla granodiorite was connected with the intrusion of the small tourmaline-aplite veins which occur in the granodiorite. Pneumatolytic action associated with the introduction of tourmaline is of a particularly intense nature, being commonly associated with the introduction of certain characteristic elements such as tin, tungsten, and boron. An attempt was therefore made to detect the presence of these elements in the kaolinised granodiorite, particularly in the neighbourhood of the tourmaline-aplite veins.

Spectrographic analysis was chosen as the means of determining the relative amounts of minor elements present in the fresh and kaolinised granodiorite, firstly because of the great sensitivity of the method, and secondly because of the impossibility of predicting in advance exactly which elements would show significant variations, and then applying suitable chemical spot tests. Spectrograms were taken on a Hilger "medium" quartz spectrograph, the region 2,000-4,000 AU extending the length of a 10-in. x 4-in. photographic plate. To obtain maximum sensitivity, the method of cathodic excitation in a low-voltage direct-current carbon arc (Strock, 1936) was used. Identification and intensity matching of lines were facilitated by the use of a projection densitometer, fitted with a ground glass screen and movable iron-arc and wavelength scale, constructed by the author on the lines of the projection micro-photometer described by Dietert and Schuch (1941).

*Procedure.*—Specimens weighing about 50 grams were selected from the various kaolinised outcrops and were treated so that representative samples, weighing no more than 20 milligrams, were obtained. In preliminary experiments, the large samples were crushed to -50 mesh, in an agate-mortar, and successively quartered until a sample weighing about 1 gram was obtained. This was crushed as finely as possible in a clean agate mortar, thoroughly mixed, and divided into minute samples for arcing. It was found necessary to burn the arc for one to two minutes at ·8 amps. in order to volatilise a 20 milligram sample, which was therefore the maximum practical sample size, as complete volatilisation is necessary in an investigation which purports to compare the compositions of heterogeneous samples.

A series of spectrograms taken from samples prepared by the above method showed appreciable variations in the relative amounts of elements present, although the samples were selected

from the same "gram sample." The variations were undoubtedly due to the presence of relatively large particles of certain minerals in the samples (particularly biotite, which is extremely resistant to crushing beyond a certain grain size). Other defects of this method of sample preparation and excitation were the heavy background due to the excitation of silicon oxide molecules, and the long period of arcing necessary to volatilise the persistent globules of molten silicates which formed in the arc crater of the lower electrode, the long exposure intensifying the cyanogen band spectrum, which obliterates the fainter lines above 3380 A.U. on the spectrogram.

In order to overcome the above disadvantages, a sampling procedure was developed in which the original large rock samples were treated with hydrofluoric and sulphuric acids (5 : 1 mixture), the solutions evaporated, ignited, and leached with concentrated hydrochloric acid. The resulting solutions were evaporated to liquids of syrupy consistency, from which small samples were taken and volatilised in the arc. It was necessary to start the arc at a low current (3 amperes) and to maintain this current until the liquid in the sample had been vaporised, after which it was possible to increase the current to 10 amperes, without generating a large quantity of steam in the sample and thereby blowing it from the crater. In this method, the elements are vaporised in the form of their chlorides, which produce clearer and more intense spectra, completely free from the silicon oxide band spectrum. The relative volatility of the chlorides results in the complete volatilisation of the sample within a one-minute arcing period. Successive spectrograms taken by this method showed a high degree of consistency, coupled with a greater sensitivity than had been obtained by arcing the powdered minerals alone.

Spectrograms were taken with a Hoffmann diaphragm fitted over the spectrograph slit, so that three successive spectrograms could be photographed on any section of the plate. The uppermost of the series was always made an iron arc comparison spectrum indispensable in calculating the wavelength of the lines in the lower spectrograms, which were taken from kaolinised and normal granodiorite, respectively. In no instance did lines of any trace element consistently appear in the spectrograms of the kaolinised material, without appearing to the same (or greater) extent in the fresh granodiorite. Among the trace elements appearing in the spectro-analyses were boron, zirconium, nickel, and vanadium. The relative amounts of the major elements in the fresh and kaolinised granodiorite, as shown in the spectrograms, corresponded with the values shown in the chemical analysis (Table II.).

## The Origin of the Kaolinisation.

### Mineralogical Evidence.

There are certain facts in the mineralogical data presented above which have a bearing on the problem of the origin of the kaolinised deposits. These facts are concerned with the type of clay mineral, the nature of the associated alteration products, and the presence or absence of pneumatolytic elements in the deposits.

(1) The clay mineral in all the kaolinised portions of the area has been shown (above) to be kaolinite, the clay mineral characteristic of low-temperature kaolinisation (Ross and Kerr, 1930). Dickite and nacrite, the kaolin minerals formed under hydrothermal and pneumatolytic conditions, respectively, are absent from the Bulla-Broadmeadows deposits, indicating that the temperature of kaolinisation was not high, probably not above 100°C. The fact that kaolinisation has taken place is in itself an indication of the presence of acids or acid gases at the time of alteration. The kaolinising action of carbonic acid has been demonstrated by Parsons (1923), that of hydrochloric acid by Schwarz and Trageser (1933), and by Gruner (1939), and that of sulphuric acid by Anderson (1935). Although much hydrofluoric acid would probably have been present if the alteration were pneumatolytic, Gruner (*loc. cit.*) has shown that this acid has apparently no kaolinising action. It is generally reported that lignic acids produced in swamp deposits have a definite kaolinising action on granitic rocks, even at normal atmospheric temperatures.

(2) From a comparison of the mineralogical features of the fresh and kaolinised granodiorite, it can be deduced that the changes that have taken place during alteration are:—kaolinisation of all felspar and some of the biotite and sericite, bleaching of most of the biotite, and production of some secondary muscovite.

Bleaching of biotite appears to be a weathering process involving the action of acids, as a similar bleaching effect can be produced by digesting the fresh mineral in hot dilute hydrochloric acid. The usual chloritic products of the atmospheric weathering of biotite are common in the solid granodiorite at Bulla and Broadmeadows, but do not occur in the kaolinised portions of the intrusion. Further evidence regarding the low-temperature nature of the alteration is provided by the absence of large quantities of muscovite or sericite from the kaolinised material. Gruner (*loc. cit.*) has shown that, in the presence of potash, kaolinite reverts to sericite at temperatures above about 400°C., so that this figure could be set as the probable upper limit of the kaolinisation temperature in this instance.

(3) The absence of pneumatolytic elements from the kaolinised granodiorite has been demonstrated (above) by comparing spectrographic analyses of the kaolinised material with those of

the fresh rock. The result supports the mineralogical evidence regarding the absence of pneumatolytic minerals from the kaolinised granodiorite. However, a serious limitation of the spectrographic method is the impossibility of detecting the presence of the negative radicals which would probably be introduced during the kaolinisation. The application of chemical tests to the kaolinised material showed that small quantities of the carbonate and chloride radicals were present but that the sulphate radical was not present in detectable amounts. Since the radicals detected are normally present in traces in all rocks exposed to atmospheric attack, their presence in this instance is of no significance in the determination of the cause of kaolinisation. A simple comparison between the relative amounts of such radicals in the fresh and in the altered rock is not possible because of their great difference in physical character. The high porosity and adsorptive capacity of the kaolinised material would naturally result in a higher concentration in it of carbonic acid and sodium chloride derived from the atmosphere, whilst the porosity of the material would permit of the ready escape of any concentration of a soluble salt or acid introduced during pneumatolysis.

Zircon is present in equal amounts in both fresh and kaolinised granodiorite, and shows no significant alteration effects. Comparison of heavy mineral concentrates prepared from fresh and kaolinised material indicated that no "pneumatolytic" minerals such as tourmaline or topaz had been introduced during kaolinisation.

The evidence provided by the minerals associated with the kaolinite is thus in agreement with the evidence in (1) above, i.e., leading to the conclusion that kaolinisation took place in an acidic environment at a temperature between 0°C. and 400°C., in the absence of any appreciable quantities of foreign metallic elements. Such conditions could have been brought about by the action of:

(*a*) Acidic liquids or gases associated with the final cooling phases of the solid granodiorite, the composition of the kaolinising agency being limited to a relatively pure acidic material containing few or none of the elements usually associated with pneumatolytic or hydrothermal attack. No mineralogical evidence could be found to support the idea that kaolinisation was due to "pneumatolysis" in the accepted sense of that term. However, the nature of the altered material is rather more compatible with the milder "hydrothermal" attack.

(*b*) Acidic liquids produced in swamp deposits on the granodiorite surface, prior to the extrusion of the Tertiary basalts.

(*c*) Acidic liquids or gases associated with the extrusion of the overlying basalts, either included in gaseous form in the flows themselves, or dissolved in the meteoric waters accompanying the eruption.

Since any one of the above agencies could have produced the mineralogical and chemical features of the deposits, the field evidence must be relied upon to decide which is the most probable hypothesis.

## Field Evidence.

Kaolinisation of the granodiorite subsequent to, or immediately preceding, the extrusion of the Tertiary basalts would have had little or no influence on the physiographic development of the area, because of the protective covering afforded by the extrusives. The fact that the kaolinisation has had no apparent influence on the physiographic development of the area in either pre-basaltic or post-basaltic time is thus strong evidence in favour of the idea that kaolinisation did not take place before the development of the land surface on which the basalts were extruded. This evidence thus opposes the "pneumatolytic" theory. There are numerous indications that the kaolinised areas have had no apparent influence on the form of the pre-basaltic land surface. Among them is the fact that within a distance of a few hundred yards, there is a difference of over a hundred feet in the elevations of the upper surface of the main kaolinised outcrop at Broadmeadows, and the upper surface of the deposit lying to the south (see Section I.). It is a significant fact that the surface of the lower outcrop shows a particularly cleancut junction with the overlying basalt, and does not exhibit the disturbed and redistributed appearance of a valley floor cut in kaolinised material.

If kaolinisation had long preceded the extrusion of the basalt, sedimentary clay deposits representing re-distributed kaolinised granodiorite would probably have been formed. No such sediments are known, the nearest clay deposits (at Campbellfield) being post-basaltic.

With regard to the angular boulders of kaolinised material at Bulla, it seems probable that the kaolinised granodiorite was too friable to have retained such shapes, which are, however, characteristic of boulders of fresh granodiorite. This suggests that the kaolinisation of the boulders in the grit took place after the deposition of the grit, presumably by some agency associated with the extrusion of the overlying basalt. A search among boulders in the grits and sands above some of the kaolin outcrops failed to reveal any fresh unaltered granodiorite.

It has been suggested (James, 1920) that the shape of the kaolinised masses at Bulla is that which is characteristic of kaolin deposits produced by pneumatolysis, but in no case was it found possible to substantiate this statement in the field, as the boundaries of the kaolinised masses are not exposed to any extent in the quarries and gullies. All that can be established with certainty is the fact that the kaolinised masses do not increase rapidly in extent with increase in depth, a point which can be deduced

from the occurrences of fresh granodiorite below and at the sides of kaolinised outcrops (K.3), (K.4) and (K.5).

The presence of tourmaline veins in the kaolin quarries on the east bank of Deep Creek has been quoted by James (1920), as positive evidence of pneumatolysis in connection with the kaolinisation. One vein occurs in each quarry, and a similar vein, passing through practically unaltered granodiorite, is now exposed in the floor of the gully on the western side of Deep Creek. All of the veins have a maximum thickness of about 1 inch, and show sharp boundaries with the surrounding rock. In structure, the veins resemble fine-grained pegmatites, as they contain relatively large crystals of tourmaline, quartz and fresh felspar. The presence of the fresh felspar could be explained, if kaolinisation were due to the action of acidic liquids percolating down from above, by assuming that the compact nature of the veins protected the felspar. If it is assumed that the veins acted as feed channels for the kaolinising agencies, as they would have done if kaolinisation were due to pneumatolysis associated with their intrusion, it becomes difficult to account for the fact that the felspar which they contain is not even partially altered.

A suggestive point in the evidence is the fact that nowhere in the area does the kaolinised material occur above the level of the basalt surface, although in several places the upper limit of kaolinisation is almost on the same level as the surface of the basalt. There are no kaolinised exposures in those portions of the granodiorite which have been removed from contact with either the basalt itself, or solutions accompanying the basalt.

At Broadmeadows, no evidence could be found to support the suggestion that kaolinisation was in any way connected with the intrusion of the dyke-like body. There is no quantity of tourmaline or any other mineral associated with pneumatolysis in it or in any part of the quarry, and there are no signs of disturbance along the contacts of the dyke with the surrounding granodiorite such as would be expected if the dyke had acted as the plane of weakness along which the kaolinising agencies had moved. No variation in the degree of kaolinisation of the surrounding granodiorite could be found within the limits of the excavation, which extends at least 70 feet in either direction at right angles to the strike of the dyke.

## Discussion.

The three possible modes of origin suggested by the mineralogical evidence may now be reviewed in the light of the above field evidence.

(*a*) Kaolinising agencies associated with the intrusion of the granodiorite would have to have been of an unusual type to comply with the mineralogical evidence discussed above. The only obvious way in which lime, magnesia, and alkalies could have been completely removed from the fresh rock, would seem to be

the contact of percolating waters with the solid granodiorite in the final cooling stage of the intrusion. It is becoming increasingly evident that there are very few definite instances of kaolinisation by agencies associated with the parent intrusions, there is even reason to doubt the evidence at Cornwall (Collins, 1909), which has long been cited as the classic example of "pneumatolytic" kaolinisation (Ross and Kerr, 1930). In the present case, the absence of minerals and trace elements typical of pneumatolytic and hydrothermal action, the nature of the clay minerals formed during the alteration, and the various points quoted in the field evidence (above) are considerable obstacles to the development of the theory.

(*b*) Kaolinisation due to the action of natural waters containing organic acids derived from decomposing vegetation in swamps is a recognised process (Kerr, 1930), and one which could have given rise to the mineralogical and chemical associations of the Bulla-Broadmeadows deposits. Field evidence, however, opposes the hypothesis, since it opposes the idea of pre-basaltic kaolinisation. The only favourable evidence available is the fact that James (1920) has shown that lacustrine deposits containing plant remains, occur between the Silurian bedrock and the overlying basalts in parts of the Bulla district. It is not improbable that similar deposits formerly occurred in depressions in the surface of the granodiorite and gave rise to acidic solutions which penetrated and kaolinised the underlying granodiorite during the period immediately prior to the extrusion of the basalts. Pre-basaltic erosion might account for the absence of the sediments from the neighbourhood of most of the kaolinised masses at present exposed.

(*c*) Although there is no conclusive evidence for the hypothesis that assigns the kaolinisation to the effect of acidic liquors associated with the extrusion of the basalts, the theory suffices to explain the mineralogical and chemical characteristics of the kaolinised masses, and is in accord with the available field evidence. There is no evidence in opposition to the idea, the only point raised by James (1920) being the fact that fresh granodiorite underlies the basalt in two places. This evidence seems rather to be directed against the idea that kaolinisation was brought about by the direct heating action of the molten basalt, a factor which it is certain would have played little or no part in the kaolinisation, because of the low thermal conductivity of the granodiorite, especially if dry. A more probable mechanism is that in which acid vapours, evolved during the extrusion of the basalts, dissolved in the magmatic and meteoric waters accompanying the event, and formed acidic solutions. The latter trapped up against the edges of the lower-lying basalt flows, from there penetrated beneath the basalts and caused the kaolinisation of the under-lying granodiorite. Such alteration would be

localised in limited areas, the location of which would be determined by a number of independent variables, such as relative altitude, permeability, temperature of the flows and solutions, and the various drainage factors which would control the collection and distribution of the active liquids.

## Conclusion.

### Summary.

The conditions under which kaolinisation took place can now be postulated with some certainty, but there is insufficient positive evidence available to permit of a definite decision being made in favour of any one of the three probable modes of origin. Although there is no conclusive evidence to discount the possibility of kaolinisation being due to agencies associated with the intrusion of the granodiorite, or to solutions produced in overlying swamp deposits, the evidence in favour of these theories is not as convincing as that which supports the view that the kaolinisation was connected with the evolution of acidic liquors and gases accompanying the extrusion of the Tertiary basalts.

## Acknowledgments.

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[PROC. ROY. SOC. VICTORIA 56 (N.S.), Pt. I., 1944.]

# ART. II.—*Contact Phenomena in the Morang Hills, Victoria.*

By A. B. EDWARDS, D.Sc., and G. BAKER, M.Sc.

[Read 10th June, 1943; issued separately 1st August, 1944.]


## Abstract.

The Morang Hills are 20 miles N.N.E. of Melbourne, and consist of a small inlier of Silurian sediments and Devonian granodiorite in an area of Tertiary Newer Volcanic basalt flows. The sediments are predominantly mudstones and shales and form a thin cover above the granodiorite. They show progressive metamorphism through spotted muscovite hornfels, and biotite-hornfels to relatively coarse-grained cordierite-biotite-hornfels as the granitic contact is approached. The north-eastern part of the contact is occupied by a sillimanite-andalusite-hornfels, rich in orthoclase.

Along its margin, and particularly at its contact with the sillimanite-andalusite hornfels, the granodiorite, which is otherwise normal, passes into a potash-rich phase, studded with giant phenocrysts of orthoclase. The extra potash appears to be derived from assimilation of the potash-rich contact rocks at a time when the magma had come to rest, and lost much of its original fluidity.


## Introduction.

The Morang Hills are situated about 20 miles N.N.E. of Melbourne, and 3 miles N.E. of Epping. The railway line to Whittlesea turns eastward between Epping and South Morang in order to by-pass them (fig. 1). The hills rise to a height of 850 feet above sea-level, and consist of Silurian sediments, intruded and thermally metamorphosed by a small stock of (?) Devonian granodiorite. The metamorphic zone extends for a quarter to half a mile from the granodiorite contact (fig. 2), and the marginal granodiorite is characterised by giant phenocrysts of orthoclase, which occur only sparsely in the interior of the stock.

The Palaeozoic rocks form an inlier 4 miles long (N.-S.) by 3 miles broad, in an area of Newer Volcanic basalt flows, and rise about 300 feet above the surrounding plain, the surface of which is broken by small "stony rises." The basalt flows came from the north, obliterating the pre-existing streams.

The Morang Hills have the form of two north-south ridges separated by a south-trending valley a quarter to half a mile wide, and 250 to 300 feet deep. The western, or Quarry Hill, ridge is 100 to 150 feet higher than the eastern ridge, and consists of hard, dense hornfels, forming a cover about 200 feet thick over the granodiorite, which is exposed in a quarry on the south-eastern side of the ridge (fig. 2). The eastern ridge consists of granodiorite, fringed by less resistant metamorphosed sediments. The short and intermittent creeks draining the hills have

built alluvial flats where they debouch on to the basalt plains. The main streams of the area are the Darebin Creek, on the west, and the Plenty River on the east. The Darebin Creek, over part of its course, follows the boundary of the Silurian sediments with the basalt.

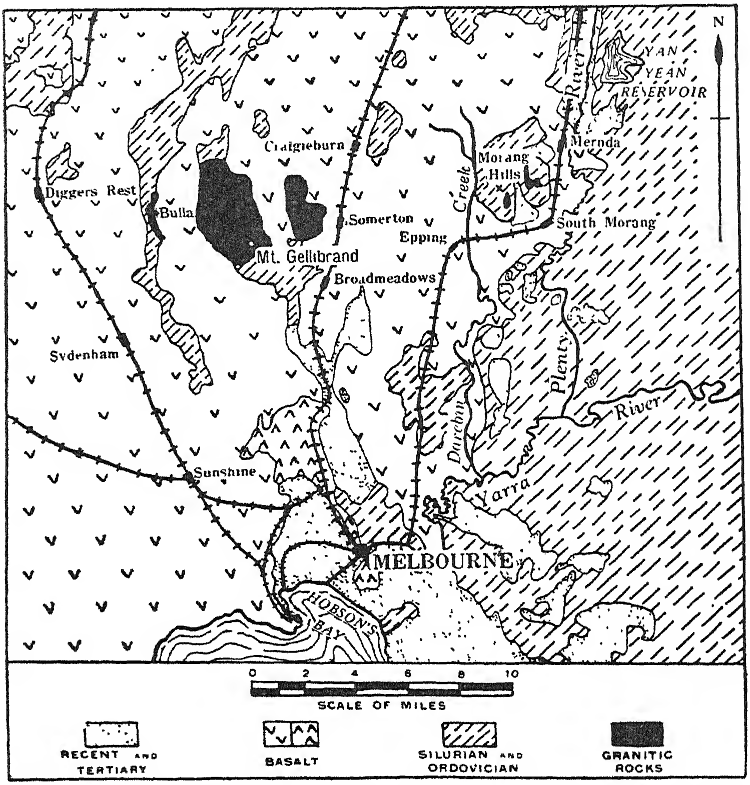


FIG. 1.—Locality Map showing the position of the Quarry Hill Area and Neighbouring Granite Rocks outcropping at Bulla and Mt. Gellibrand. Drawn, with modifications, from the Geological Map of South Central Victoria (Handbook for Victoria, 1935).

The area was first geologically surveyed by Etheridge in 1868, in connection with the preparation of Quarter Sheet No. 2 N.E. Jutson (1910) referred to it briefly in his study of the Plenty River, and a brief note on the Morang granodiorite has been published by Howitt (1936). Kenny (1937) reported upon the gold-bearing alluvial lead at South Morang, and Skeats and James (1937) compared the stony rises of the basalt plains with those of the Colac District.

Interest in the area attached chiefly to the metamorphic changes induced in the Silurian sediments, and to the hybrid origin of the margin of the intrusion.

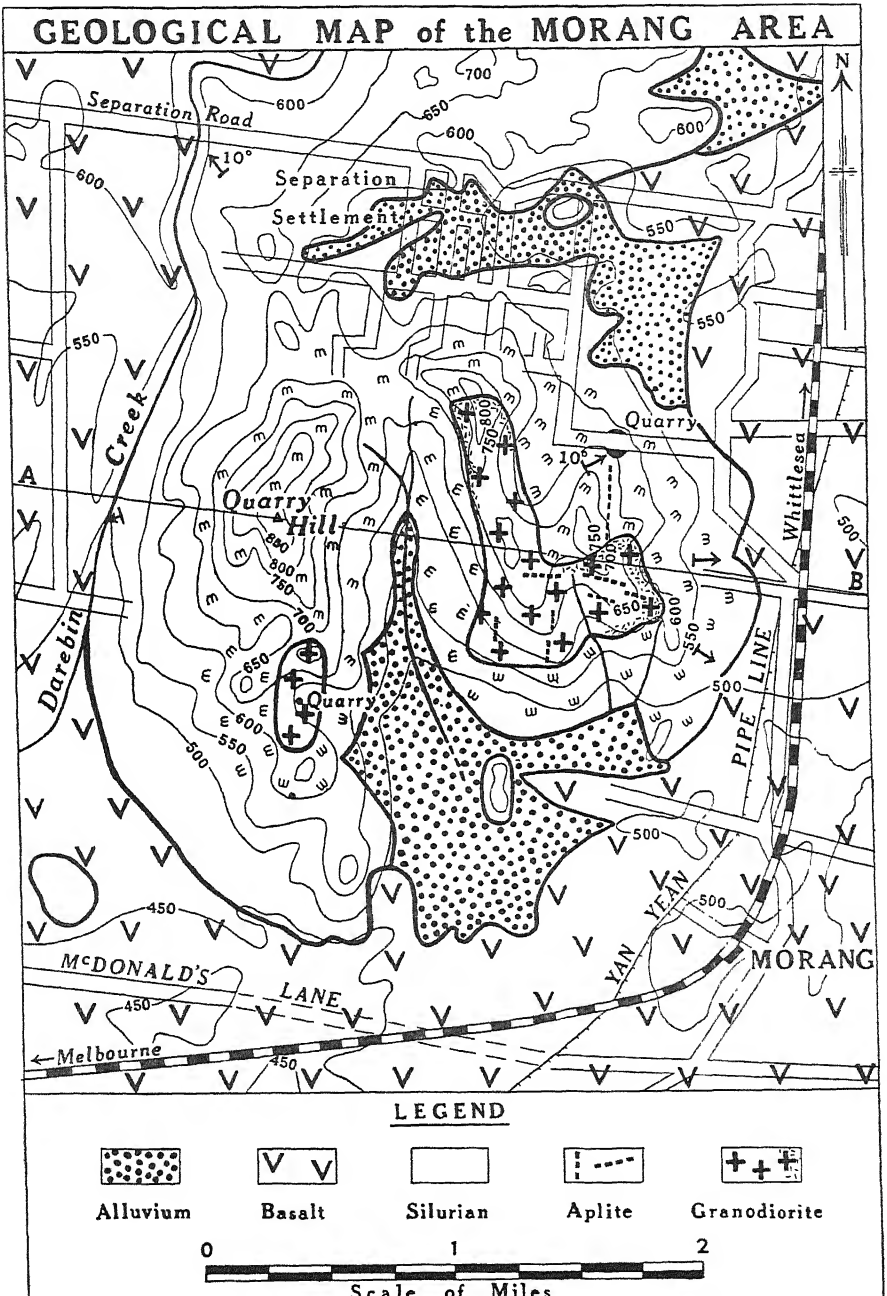


FIG. 2.—Geological Map of the Morang Area, based on Military Survey Sheet of Yan Yean and Quarter Sheet No. 2 N.E. of the Victorian Geological Survey.

## The Silurian Sediments.

The Silurian sediments consist of finely-bedded mudstones and shales, with an occasional interbedded sandstone band. Their geological relationships are largely masked by soil and hillwash, but such dips as could be found indicate that they occur in a dome-like structure with outward dips of from 10°-20° (fig. 2). The best exposures are in the Country Roads Board quarry, to the north-east of the eastern outcrop of granodiorite, and on Separation-road near the bridge over Darebin Creek. No fossils have been found in the Morang Hills, but there can be little doubt that they represent a continuation of lithologically similar, fossiliferous rocks of Silurian age which outcrop a few miles to the north (Jutson, 1908).

## Contact Metamorphism.

### Mudstones and Shales.

The successive stages in the metamorphism of the original argillaceous shales and mudstones are best seen between Darebin Creek and the western granodiorite outcrop. The unaltered sediments are fine-grained rocks consisting of varying proportions of quartz, chlorite, and sericitic material, with lesser amounts of accessory iron ores, and detrital zircon, rutile and sphene. In the outer aureole, the first signs of metamorphic change are induration of the sediments and the appearance of small wisps of secondary mica. With increased recrystallization, the amount of secondary mica formed increases, and the mica tends to segregate, so that the rocks appear spotted. The spots are rich in pale-green and white mica, and are spherical to ovoid in shape. They have ill-defined boundaries, and merge into the surrounding matrix. Closer to the contact, but still at about 300 yards or more from it, the spotted texture becomes pronounced, owing to the increased size of the secondary mica plates. In places the spots consist largely of limonite, formed from the weathering of iron ores associated with the segregated mica plates. Generally, however, and particularly in the more arenaceous rocks, they are made up chiefly of clear white or pale yellowish-green mica, and are separated by interstitial areas rich in quartz. According to Tilley (1924, p. 28), such spots in the contact rocks of an outer aureole are due to the selective aggregation of directional minerals under the influence of interstitial solutions, derived in part from the sediment and possibly in part from the magma.

*Zone of Biotite Development.*

Closer to the contact, but in some parts of the aureole at distances of almost 300 yards from it, biotite begins to make its appearance as small plates, some of which are bleb-like and are included in quartz crystals. The quartz grains of the sediments have grown larger, and the white mica now forms laths and plates

of muscovite. The appearance of biotite marks a significant change in the nature of the metamorphism, from one involving only recrystallization of existing minerals, to one involving chemical reconstruction of the rock, and the formation of new minerals (Tilley, 1924, p. 29). The biotite is formed from chemical reactions involving the chlorite, sericitic material, iron oxides, rutile and silica of the mudstones and shales, which now lose much of their residual structures, and pass into more or less spotted hornfels. At this stage, the titanium minerals in the sediments have recrystallized to form numerous minute and scattered crystals of rutile, with sporadic crystals of brookite, and rare anatase. The detrital sphene has recrystallized to form clusters and strings of granular sphene, and occasional small prisms of tourmaline make their appearance. These indicate slight pneumatolysis. The iron ores and zircons remain unchanged.

*Zone of Cordierite Development.*

Still closer to the contact cordierite makes its appearance. The zone of cordierite development is usually from 200 to 250 yards from the contact, and in one place is a quarter of a mile from an observed contact. This exceptional occurrence is found at Country Roads Board quarry, and suggests that the granodiorite is close to the surface at this locality.

The rocks are still spotted in this zone of the aureole, but the spots now consist of poikiloblastic cordierite crystals, which are replacing the original micaceous spots. The cordierite crystals have irregular outlines, and show sixfold twinning. They contain innumerable inclusions, consisting of iron-ore dust, minute flakes of biotite and plates of muscovite. The inclusions are often confined to the centres of the cordierite crystals, the margins of the crystals being clear. The matrix of the rock consists of numerous laths and small plates of biotite and granular crystals of quartz, together with abundant minute crystals of rutile, lesser brookite and sphene, and some waterworn zircons. The rocks may be classed as cordierite-biotite hornfels, with fine-grained granoblastic texture. The biotite, though still present only as minute crystals, has passed the bleb stage. The abundance of cordierite, and the absence of andalusite from this zone is probably due to the high chlorite content of the original sediments (Tilley, 1924, p. 31). Where rocks in this zone were originally rich in sericitic material, they have formed sericite-biotite-quartz hornfels, comparable with those developed at Bulla (Tattam, 1925, p. 233), and lacking in cordierite.

With more intense metamorphism, the cordierite hornfels and biotite-quartz hornfels become somewhat coarser-grained, and their iron ore grains become fringed with biotite as they approach the actual contact; but no additional new minerals make their appearance, other than occasional grains of diopside.

*Sillimanite-Andalusite Rocks.*

Along the northern contact of the bulge on the eastern side of the more easterly granodiorite outcrop, varieties of thermally altered rocks occur which have not been observed elsewhere in the aureole. They appear to have been formed from argillaceous sediments which were rich in sericite, but much poorer in chlorite than the sediments which gave rise to the cordierite hornfels or the biotite-quartz hornfels. Most conspicuous among them is a porphyroblastic rock, in which the spots, which are up to 5 mm. across, consist of felted masses of sillimanite fibres, accompanied by plates of colourless muscovite and occasional flakes of biotite. Within the spots are found occasional frayed and embayed crystals of andalusite. These inclusions, in conjunction with the commonly idioblastic form of the spots, indicates that the spots once consisted entirely of andalusite, and that with progressive metamorphism the andalusite has been largely converted into sillimanite. Orthoclase is present as numerous granular crystals and xenoblasts in the matrix. Tilley (1924, p. 60) has shown that orthoclase can be formed from interaction of sericite and silica (quartz), with the production of andalusite as a by-product, or by the reaction of biotite with quartz. The latter reaction, however, involves the simultaneous formation of cordierite, and since no cordierite has been found in the sillimanite-andalusite rocks at Morang, it is thought that the orthoclase and the original andalusite developed from original sericite. Any soda in the sericite has formed occasional crystals of oligoclase, or has entered into solid solution in the orthoclase. The orthoclase and oligoclase occasionally occur intergrown in diablastic structures.

The alkali content of the rock is $K_2O$ 5·19, $Na_2O$ 1·99. The potash content is high, but not unduly high for mudstones, as compared with other analysed Palaeozoic mudstones and slates from Victoria (Howitt, 1923). The soda content, however, is unusually high for a mudstone so rich in potash, so that some proportion of the alkalis may have been introduced from the granodiorite. If this occurred, it is likely that soda rather than potash was introduced, since, as shown later, the granodiorite magma appears to have been saturated with soda, but undersaturated with respect to potash.

Brown and reddish-brown biotite, quartz, and, occasionally, tourmaline, are the other chief constituents of the sillimanite-andalusite hornfels. The biotite has been partially altered to pale-coloured chlorite, with the precipitation of rutile as long needles and as sagenitic webs. The accessory minerals present are waterworn zircons, with occasional rutile, brookite and sphene crystals, and in some specimens, abundant iron ores.

Associated with this distinctive spotted hornfels are arenaceous and muscovite hornfelses, of variable grain size, which characteristically contain abundant limonite, derived from the fine-grained iron ores of the original rock. They are soft, crumbly rocks, which are much more readily eroded than the dense, quartz-biotite hornfels and cordierite hornfels of the Quarry Hill ridge.

ARENACEOUS SEDIMENTS.

Arenaceous sediments, though present in the Morang aureole, are of such restricted occurrence that it is impossible to trace the successive stages of their metamorphism. In general, the hornfelses derived from them resemble those derived from the more sandy argillaceous rocks, but contain more quartz. Some approach quartzites in composition and consist of a mosaic of interlocking quartz crystals, with occasional interstitial areas of greyish-brown, crypto-crystalline material which appears to be a mixture of sericite and chlorite. Others, originally richer in chlorite and sericite, contain wisps and plates of muscovite, and of pale-green and pale-brown mica. A feature of the arenaceous hornfelses is that they almost completely lack the grains of iron ore that are so abundant in many of the altered argillaceous rocks. Rutile, brookite, and sphene are similarly lacking, though occasionally detrital crystals of these minerals are found associated with well-defined strings of waterworn zircon crystals lying along an original bedding plane. Another difference from the argillaceous hornfelses is the small number of spotted structures in the arenaceous hornfels. When spots are present, they consist of clots of muscovite plates.

Along the eastern ridge, scattered boulders of brecciated, fine-grained, arenaceous hornfels have been found both north and south of the eastern bulge in the granodiorite outcrop. The angular fragments of hornfels, together with occasional fragments of quartz are cemented together by limonite, and some of the hornfels fragments are traversed by small quartz veins. The presence of the small quartz veins suggests that the brecciation occurred in the interval between metamorphism and the late stages of consolidation of the granodiorite.

GRAIN SIZE.

The hornfelses generally show an increase in grain size as the granodiorite junction is approached. Thus, in a micaceous variety, 300 yards from the contact, the quartz grains average about 0·04 mm. across; in a spotted hornfels, 200 yards from the contact, they are 0·08 mm. across; in an arenaceous hornfels, 100 yards from the contact, they are 0·1 mm. across; while in the sillimanite-andalusite hornfels at the contact the average size of the quartz grains is between 0·4 and 0·8 mm. across. For com-

parison, it may be noted that quartz crystals in the granodiorite average 2·5 mm. in diameter, and are up to 4 mm. across in the porphyritic marginal granodiorite, while in the xenoliths they range between 0·8 and 1·5 mm across. The rocks close to the granodiorite are not invariably coarse-grained, however. Some are little coarser-grained than the sediments from which they are derived, and according to Tilley (1924, p. 64) neither differences in original grain size nor differences in composition can account for these grain size anomalies.

## LAMINATED HORNFELS.

The increase in grain size with more intense metamorphism arises from an increased range of diffusion, and this leads to a corresponding destruction of residual or palimpsest structures. Where the original sediments were finely bedded or current-bedded, with alternating beds of variable composition, the hornfels derived from them show a corresponding lamination, bands of arenaceous hornfels alternating with bands of argillaceous hornfels. There may be as many as 30 such laminae to the inch, and in some of the laminae lamellar minerals like biotite and muscovite are arranged in sub-parallel fashion. This type of structure persists into the zone of cordierite development, but close to the contact the complete recrystallization and reconstitution of the rocks has generally destroyed all traces of it. It is best seen in weathered hornfels in the Country Roads Board quarry (fig. 3) and on Quarry Hill (fig. 4).

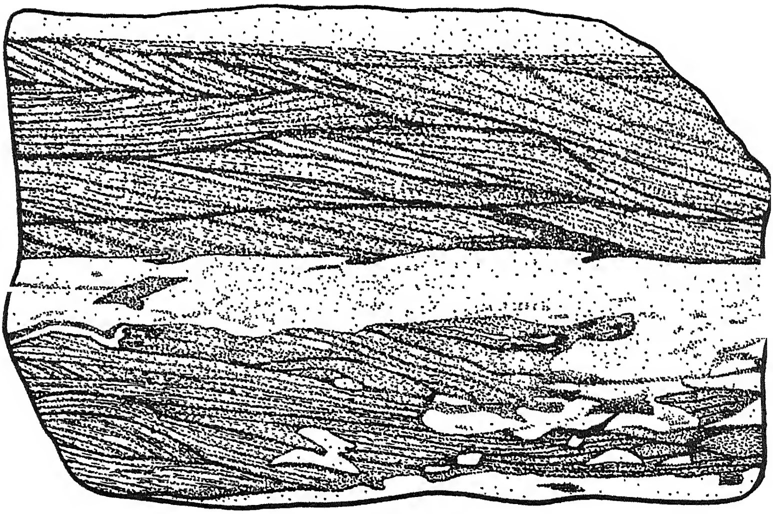

FIG. 3.—Sketch of Laminated Hornfels showing Preserved Cross-bedding Structures. From Country Roads Board Quarry.

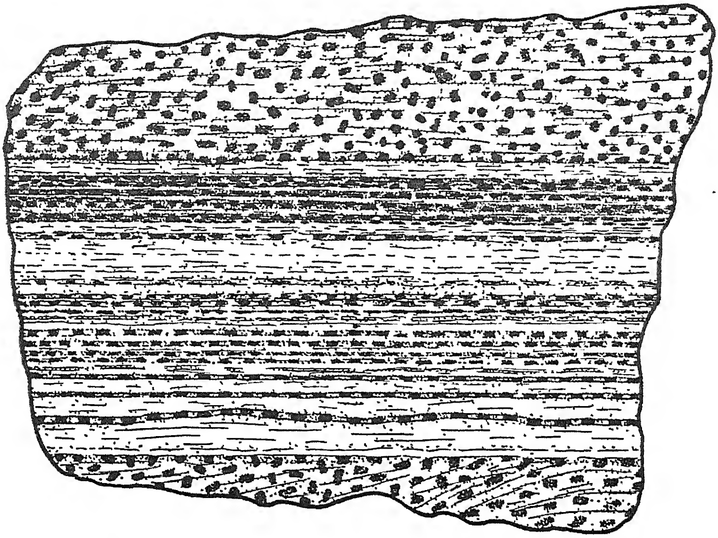

Fig. 4—Sketch of Banded Hornfels from Quarry Hill, showing Bedding Structures preserved by narrow alternating bands of Spotted Hornfels and Arenaceous Hornfels.

*Remarks on the Contact Metamorphic Zones.*

The contact aureole at Morang resembles in many respects that at Bulla (James, 1920; Tattam, 1925), but there are some points of difference. The temperature of the Morang intrusion was not very high, since hydrated minerals are present in the contact rocks, and persist right up to the granodiorite junctions. The contact rocks at Morang, moreover, are all free-silica, non-calcic hornfels, and the characteristic rocks of the aureole are argillaceous types. As a result, spinellids are absent, and corundum is rare. Corundum, armoured about with mica, has been observed in only one section. The biotite "beards" fringing the ilmenite grains indicate that this mineral contributed to the formation of biotite, much as in some igneous rocks. Small amounts of lime in the original sediments have recrystallized to form a few minute grains of pale-green diopside and occasional crystals of oligoclase. The original detrital sphene in the partially metamorphosed sediments recrystallized to form sphene granules in the more intensely altered rocks; and the abundant apatite in the hornfelses is largely derived in the same way from detrital apatite, but some phosphorus seems to have been introduced from the magma, since close to the contact the apatite occasionally occurs in small veinlets. Tourmaline is only sparsely developed, and topaz is doubtfully present in small amount, showing that the inner contact rocks have been subjected to only slight pneumatolysis.

## Xenoliths in the Granodiorite.

Xenoliths derived from the sedimentary rocks are relatively numerous in the more easterly exposure of granodiorite, but not in its porphyritic margin, despite the prevalence of xenocrysts and products of assimilation in this zone. The xenoliths range in size from less than an inch up to 18 inches in diameter. They show various stages of granitisation (Baker, 1936), and are sometimes foliated, the foliation resulting from an initial variation in composition of alternating lamellae such as gave rise to the laminated hornfelses.

In the early stages of reconstitution, the xenoliths consist of granular rocks not very different from the hornfels close to the contact. In some instances, the invasion of material from the granodiorite magma has caused the formation of phenocrysts of oligoclase and poikiliths of orthoclase and quartz. With advancing reconstitution, coarser-grained patches develop in the originally fine-grained xenoliths, and these coarse-grained areas spread until the whole xenolith has a granitic texture. The porphyritic intermediate stages of the transition commonly resemble biotite-rhyodacites, both in texture and in mineral composition.

The completely reconstituted xenoliths can be divided into three groups according to their mineral composition:—

(1) orthoclase-biotite-quartz rocks, with little or no plagioclase;

(2) oligoclase-biotite-quartz rocks, with little or no orthoclase; and

(3) oligoclase-hornblende-biotite-quartz rocks, in which there is little or no orthoclase.

The xenoliths of group 1 represent potash-rich contact rocks which have been further recrystallized, without marked metasomatic alteration. Those of group 2 appear to have been derived from similar rocks, but have undergone metasomatic changes, soda and lime from the granodiorite magma having been substituted for the potash of the original hornfels. In the group 3 xenoliths, metasomatic alteration has gone further, and the biotite has also been affected. In the least reconstituted rocks, the biotite first appeared as small blebs, which with increasing granitisation, grew first into small laths, which collected into decussate patches, and then "coalesced" or were "welded" into large plates. Finally, the biotite commenced to react with the lime brought in by the invading magmatic solutions, and changed over to hornblende. At the same time, the titanium in the biotite was thrown down as sphene. The hornblende formed by the reaction grew into large plates showing sieve structure, and enclosing remnants of the original biotite, and the precipitated

sphene crystals. The $K_2O$ of the biotite presumably passed into the granodiorite magma along with the $K_2O$ from the original orthoclase.

Where clots of ferromagnesian minerals came into direct contact with the granodiorite magma, they tended to react with it and form pink almandine garnets (Edwards, 1936). Zircon is the only mineral in the original sediments which resisted recrystallization, and well-rounded, waterworn zircons are found in each class of xenolith. In the completely reconstituted xenoliths, however, idiomorphic zircons surrounded by pleochroic haloes are also present, as inclusions in both the hornblende and the biotite, and such zircons were presumably introduced from the granodiorite magma. A common feature of all the xenoliths is the abundance of rods and needles of apatite, which are included in later-formed minerals, and represent recrystallized lime phosphate from the original sediments. A second generation of apatite crystals, appearing in some xenoliths in the form of much larger crystals represents lime phosphate introduced from magmatic solutions soaking through the xenoliths.

## Granodiorite.

The granodiorite is a mesocratic, medium to fine-grained rock, with occasional phenocrysts of orthoclase up to ½-inch across. It consists of allotriomorphic and interstitial quartz grains, zoned and twinned oligoclase showing partial alteration to sericite, partly kaolinised orthoclase, biotite, and occasionally hornblende. The hornblende is derived from the assimilation of xenoliths, in which it was formed during their chemical reconstitution by a substitution of lime from the magma for the potash of original biotite. The biotite is occasionally chloritised, and associated with calcite. It carries inclusions of zircon surrounded by intense pleochroic haloes, and of ilmenite and small apatite crystals. The apatite also occurs as large individual crystals not enclosed in biotite. The biotite also contains inclusions of a pale yellowish-green weakly pleochroic micaceous mineral, which is surrounded by pronounced pleochroic haloes 0.02 mm. wide. The individual inclusions are too small for precise determination, but the mineral appears to be one of the radioactive, light-coloured micas (Johannsen, 1914, p. 323). It has a maximum absorption in the same direction as the biotite, but has a lower refractive index. Its birefringence is high, and it shows anomalous extinction. Orthite is present occasionally (Baker, 1937, p. 56, fig. 8). Small amounts of pyrrhotite and molybdenite occur in joint planes in the quarry on the western ridge.

The heavy minerals are listed in Table 1, where they are compared with the heavy minerals of the neighbouring granitic rocks of Mount Gellibrand and Bulla. The heavy mineral suites of the

three rocks are closely comparable, particularly with respect to the essential heavy minerals, and the primary accessory minerals. The separation of the heavy minerals was carried out in bromoform of specific gravity 2.88, in the manner described by Baker (1942, p 201).

A chemical analysis of the rock (Table 2, No. 2) shows that it is a typical granodiorite, and that it closely resembles in composition the granodiorites of Bulla and Mount Gellibrand (Table 2, Nos. 3 and 4).

Jointing in the granite is not conspicuous. The most prominent planes are vertical and strike N.W.-S.E. Subsidiary joints strike E.-W. and N.10°E. Tors formed on weathering are small, rarely exceeding 10 feet in height.

TABLE 1.—Showing heavy mineral index numbers and assemblages of three related granodioritic rocks in South-Central Victoria.

| — | South Morang (West Outcrop) | Bulla. | Mt. Gellibrand, Broadmeadows |
|---|---|---|---|
| Index Number | 11·68 | 10·71 | 9·42 |
| Actinolite | .. | | V |
| Apatite (colourless) | a | a | a |
| Apatite (pale yellowish-green) | V | o | r |
| Biotite | a | A | A |
| Brookite | X | V | .. |
| Chlorite | o | A | o |
| Corundum | V | .. | . |
| Epidote | X | .. | r |
| Garnet | o | o | V |
| Gold | .. | . | V |
| Hematite | r | . | .. |
| Hornblende | o | . | .. |
| Ilmenite | o | r | o |
| Magnetite | . | . | V |
| Orthite | X | .. | .. |
| Rutile | X | .. | o |
| Sulphides | o | r | o |
| Tourmaline | V | .. | V |
| White Mica | C | C | o |
| Zircon (colourless) | C | C | C |
| Zircon (pale yellow) | V | V | C |
| Zircon (inclusions in) | C | r | o |

*Key.*—A—very abundant; a—abudant; C—common, o—occasional; r—rare, V—very rare; X—recorded from thin sections.

The heavy mineral assemblages of neighbouring granodiorites in South-Central Victoria (Table 1) were obtained from the separation of crushed, fresh, representative rock in bromoform of specific gravity 2.88 and their index numbers obtained in the manner described elsewhere (Baker, 1942, p. 201). The brookite noted in the Bulla granodiorite is recorded from one grain only of that mineral, while minerals marked X in Table 1 only appeared in thin sections of rocks from certain portions of the outcrops.

TABLE 2—Showing chemical analyses of neighbouring granodioritic rocks in South-Central Victoria.

| — | I. | II | III. | IV. | V |
|---|---|---|---|---|---|
| $SiO_2$ | 66·30 | 69·17 | 66·13 | 67·75 | .. |
| $Al_2O_3$ | 16·42 | 15·95 | 16·83 | 16·11 | .. |
| $Fe_2O_3$ | 0·52 | 0·88 | 1·11 | 0·50 | .. |
| FeO | 3·00 | 3·64 | 4·17 | 4·00 | .. |
| MgO | 1·05 | 1·12 | 1·83 | 0·79 | .. |
| CaO | 1·85 | 3·04 | 3·26 | 2·68 | .. |
| $Na_2O$ | 2·65 | 2·64 | 2·25 | 2·60 | 1·99 |
| $K_2O$ | 6·00 | 3·07 | 3·14 | 3·42 | 5·19 |
| $H_2O$ | 0·42 | 0·36 | 1·91 | 1·16 | .. |
| $TiO_2$ | 0·44 | 0·77 | tr | 0·85 | .. |
| MnO | 0·05 | 0·03 | 0·07 | tr. | .. |
| $P_2O_5$ | 1·12 | 0·02 | tr. | 0·09 | .. |
| Cl | | | . | .. | .. |
| Total | 99·82 | 100·69 | 100·70 | 99·95 | .. |
| Sp. Gr. | 2·67 | 2·66 | 2·68 | 2·68 | .. |

I.—Porphyritic marginal phase of the granodiorite, South Morang. (Analyst: A. B. Edwards)
II.—Quarry Hill granodiorite, South Morang (Analyst: F J. Watson).
III.—Bulla granodiorite (Analyst: F J. Watson) (James, A., 1920).
IV.—Mt. Gellibrand "adamellite", Broadmeadows. (Analyst H. C. Richards) (Stillwell, F. L. 1911).
V.—Metamorphosed Silurian shale adjacent to porphyritic granodiorite.

PORPHYRITIC MARGINAL PHASE OF THE GRANODIORITE.

The marginal portion of the granodiorite in the eastern outcrop is pronouncedly porphyritic, the phenocrysts consisting of anhedral orthoclase crystals which are up to 3 inches long and 1 to 2 inches wide.

This border phase appears to be purely local as shown in fig. 2, but it may extend along the roof and walls of the stock as suggested in fig. 5.

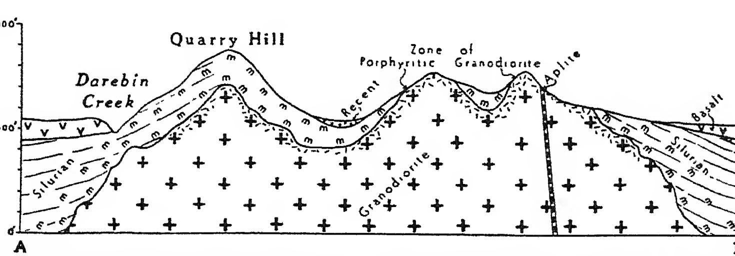


Fig. 5.—Geological sketch section through Quarry Hill, showing probable space form of the granodiorite, porphyritic zone and relationship to the invaded Silurian country rock.

The orthoclase phenocrysts show a random arrangement, and are not at all corroded. They contain lamellar perthite intergrowths of albite, and poikilitically enclose crystals of biotite, oligoclase, quartz, zircon, apatite, ilmenite, muscovite, andalusite

and garnet. The andalusite is derived from the disintegration of xenoliths of the sillimanite-andalusite hornfels, while the garnet is a reaction product of the granodiorite magma with the ferromagnesians of the xenoliths (Edwards, 1936, p. 44).

The groundmass of the border phase consists of contaminated granodiorite. In it oligoclase predominates over orthoclase, and associated with these minerals are biotite, muscovite, garnet, brookite, andalusite, corundum and diopside. In addition, there are numerous remnants of granitised xenoliths. Much of the biotite is a reddish-brown colour, and resembles that in the hornfels, from which, presumably, it is derived, as also are certain quartz grains containing clouds of dust-like inclusions. In parts of the marginal zone, abundant muscovite is mainly derived from the assimilation of muscovite hornfels at the adjacent contact, as is the andalusite and corundum. These portions of the granodiorite also contain a pale green mica, reddish-brown biotite, and xenocrysts of material identical with the sillimanite-mica idioblasts found in the nearby sillimanite-andalusite hornfels. The pale-green mica has been formed by the bleaching of biotite, and the titanium, which was taken up by the biotite during its development under thermal metamorphism, has been thrown down as rutile needles in the cleavages, where it forms sagenitic webs.

A chemical analysis of the marginal phase (Table 2, No. 1), shows that it is distinctly richer in potash, and in phosphorus, than the normal granodiorite (Table 2, No. 2), and that it is poorer in lime, but otherwise has many features in common with it.

The enrichment in potash can have developed in either of two ways. It may represent a marginal concentration of potash-rich residual magma, or it may have arisen through the assimilation of potash-rich sediments by a magma almost at rest. The abundance of xenocrystic matter in the marginal phase, and the established potassic character of the adjacent contact sediments leaves little doubt that part at least of the potash was derived from this second source.

The replacement of orthoclase by oligoclase, and of biotite by hornblende, in certain of the xenoliths in the granodiorite away from the porphyritic margin indicates that the granodiorite magma as a whole was more or less undersaturated with respect to $K_2O$, since it could take additional $K_2O$ into solution without immediately reprecipitating it as potash minerals. Occasional coarse crystals of orthoclase do occur through the main mass of granodiorite, suggesting that the degree of undersaturation was only slight, but they are neither as large nor as abundant as those in the marginal zone. Presumably, therefore, the magma was

sufficiently fluid for the potash obtained from the xenoliths to be more or less evenly distributed through the magma by diffusion and by convection currents.

The size of the phenocrysts of orthoclase in the marginal zone, coupled with their late formation, indicates that they must have crystallized rapidly. This establishes that the marginal zone, unlike the core magma, was saturated with $K_2O$, and that addition of extra $K_2O$ from the assimilated xenoliths led to its rapid re-precipitation as orthoclase.

As long as xenoliths could migrate into the interior of the granodiorite stock, their potash content could be dispersed through a considerable volume of magma, and the increase in potash at any one point would be slight, and without any marked effect; but with a cessation of such movement, any potash added would accumulate in the limited volume of magma adjacent to the contact, where saturation would soon develop, and lead to re-precipitation of the potash.

In the marginal zone, the lack of parallel arrangement of the orthoclase crystals, and the abundance of xenocrystic "strew" indicates that the magma was not subject to convectional currents or differential movements, and had lost the fluidity which enabled earlier formed xenoliths to sink or be swept out into the interior of the stock, so that there was no strong force which would sweep away the products of the assimilation that was clearly in progress. Moreover, the apparent loss of fluidity would suggest a restricted range and rate of diffusion for dissolved substances such as potash, which would then develop local over-saturation and precipitate as large phenocrysts of orthoclase. Such a cessation of movement, and reduction of fluidity might be expected to develop at the margin as the stock cooled.

### Dykes and Veins.

Occasional aplite veins from 1 to 20 feet wide traverse the granodiorite, and more rarely the contact rocks. They can be traced for only short distances. Aplite also forms occasional patches and stringers threading through the granodiorite. The aplites have fine to coarse saccharoidal textures, and consist chiefly of orthoclase, interlocked with quartz crystals, and with lesser amounts of idiomorphic oligoclase, scattered plates and radial aggregates of muscovite, occasional plates of altered biotite, and rare crystals of ilmenite, apatite and zircon. Fine-grained, graphic pegmatite of much the same composition occurs as scattered boulders near the eastern margin of the eastern granodiorite contact, and small veins of quartz, seldom more than 3 inches wide, are occasionally present. Small amounts of orthoclase are associated with the quartz in vughs in these veins.

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[PROC. ROY. SOC. VICTORIA 56 (N.S.), PT. I., 1944.]

# ART. III.—*Ecological Studies No.* VII. *Box-Ironbark Association.*

By REUBEN T. PATTON.

[Read 8th July, 1943; issued separately 1st August, 1944.]

## Introduction.

The Box-Ironbark forests of the State consist of the Red Ironbark, *Eucalyptus Sideroxylon,* White Ironbark, *E. leucoxylon*, and Grey Box, *E. hemiphloia*. In places, other species may be present, as Red Box, *E. polyanthemos*, Red Stringybark, *E. macrorrhyncha*, and less commonly Long-leaved Box *E. elaeophora,* but these three belong to another association which replaces Box-Ironbark as rainfall increases. Another species Yellow Box, *E. melliodora*, may also occur, but its presence usually indicates a local change in soil conditions and as a rule it is accompanied by a greater amount of grassland.

The Box-Ironbark forests extend discontinuously along the northern foothills of the Divide from Chiltern in the north-east to Stawell in the west. The three trees constituting the association have individually much wider distributions than in the Box-Ironbark forests themselves and are to be found in widely differing habitats.

Grey Box is also essentially a tree of the grasslands of the north where it forms true Savannah. Nearer the foothills of the Divide, the trees come so close together as to constitute Savannah Forest. It is impossible to mark a boundary between this type of forest and true forest. Grey Box is associated with grassland from regions near Tallangatta in the north-east to the south western boundary of the Wimmera. It does not extend southward into the higher elevations but it is only a few miles from the top of the Divide at the Kilmore Gap. Grey Box, however, reappears to the south of the Gap at Broadmeadows where it is again associated with grassland. It occurs at Melton and from there it extends for a few miles both to the south and west of Bacchus Marsh. Grey Box is limited to these restricted areas south of the Divide although grasslands are there abundant.

White Ironbark, which is sometimes known as Yellow Gum, also has a wide distribution north of the Divide, although more restricted than Grey Box. It is plentiful at Mangalore in the east and extends westwards to the Wimmera where it joins Grey Box on the grasslands. White Ironbark, however, is not found with Grey Box on the northern plains. South of the Divide, White Ironbark has a very limited range. It is found in the

Plenty River area and appears again north-west of Melton where it is associated with Grey Box but a characteristic Box-Ironbark forest does not develop. White Ironbark extends southwards along the eastern side of the Brisbane Ranges and is found as far west as Meredith where it occurs on grassland.

Red Ironbark, on the north of the Divide, unlike the other two tree members, is restricted to the association, but in the south it has a very extensive and very curious disconnected distribution. The climatic conditions of some of these southern localities are widely different from those of the northern areas. In the east of the State, Red Ironbark is fairly plentiful at Gipsy Point, on Mallacoota Inlet, and a few trees occur about 3 miles west of Cann River township. From Orbost to Bairnsdale it is plentiful in places, and here both Red Box and Red Stringybark also occur. Further west it also occurs at Toongabbie. To the north-east of Melbourne, Red Ironbark is fairly common in the Panton Hill district, where it again associates with Red Box and Red Stringybark. To the west of Melbourne there is a localized occurrence of rather stunted trees on the hills to the north of Melton, and further west it appears again at Ingliston, just beyond Bacchus Marsh. It is reported to occur in the forest to the south of Ballarat, but the author has not been able to confirm this. In the Melton area, although both Grey Box and White Ironbark are present, they do not mix with Red Ironbark. In view of the hot dry summers and the continental climate generally experienced north of the Divide, these occurrences of Red Ironbark in the south are surprising, but still more so is the presence of this species right at the seaside where it is under the influence of an oceanic climate. To some extent the presence of it at Jemmy's Point, Lakes Entrance, may not be wondered at as it occurs plentifully immediately to the north. However, the occurrence at Airey's Inlet, in the Otway Peninsula, is widely separated from any other.

This association is of great economic importance, since the three trees constituting it, provide very heavy durable timbers and excellent firewood. They also occupy areas which are quite unsuitable for any other purpose, on account of the stony ground. The Box-Ironbark forests are of interest since in many instances they are immediately succeeded on the northern side by patches of Mallee although the main block of the Mallee is very distant and occurs on a very different type of soil. These isolated patches of Mallee occur on the same geological formation as the Box-Ironbark and immediately adjoin. Often Red Ironbark penetrates these patches of Mallee scrub. The contrast in height from Box-Ironbark to Mallee scrub is very striking, and no satisfactory evidence is as yet forthcoming to give any explanation for the sudden change in the several occurrences. Mallee is associated with the Box-Ironbark Association at Rushworth, Bendigo, Ingle-

wood, Wedderburn, and St. Arnaud. It is of interest that just to the west of Melton where the three tree members of the association occur there is also a patch of Mallee, the only occurrence south of the Divide.

Nearer to the Divide the Box-Ironbark is succeeded by the Red Box-Red Stringybark association which is also strongly developed south of the Divide. Generally speaking the trees of this latter association, although growing under more favourable climatic conditions, are smaller in height than those of the Box-Ironbark association. The distribution of the various occurrences of the association is shown in fig. 1. This paper chiefly concerns itself with a general survey of the whole area where Box-Ironbark occurs and where detailed studies have not yet been made.

## Physical Environment.

### CLIMATE.

RAINFALL.

All the individual occurrences of Box-Ironbark receive very similar amounts of rainfall, although they are spread over an area some 225 miles long by a maximum width of about 62 miles. The greatest amount is received by the most easterly area of the association. The annual rainfall received by the various Stations situated in the Box-Ironbark areas (fig. 1) is given in Table I.

TABLE I.—ANNUAL RAINFALL OF STATIONS IN BOX-IRONBARK AREAS.

| Station. | Mean Annual Rainfall. |
|---|---|
| Chiltern | 26·75 inches |
| Peechelba | 23·46 " |
| Rushworth | 19·96 " |
| Heathcote | 22·48 " |
| Bendigo | 21·24 " |
| Maldon | 23·17 " |
| Inglewood | 18·07 " |
| Dunolly | 19·98 " |
| Maryborough | 20·34 " |
| Talbot | 21·25 " |
| Wedderburn | 18·68 " |
| St. Arnaud | 19·36 " |
| Stawell | 21·27 " |

It will be seen from Table I. that the annual rainfall varies from slightly over 18 inches to less than 24 inches with the exception of Chiltern, which lies close to the Eastern Highlands. The southern limit of this association is definitely fixed by climatic conditions, for, where the same soil conditions continue into the higher rainfall and cooler temperature areas, the Box-Ironbark is replaced by Red Stringybark-Red Box association. The northern limits are not well defined for here the boundary is often fixed by a

change in the geology. The presence of Mallee, however, on the northern side of several of the occurrencs of this association does suggest that a climatic limit had been reached. None of these patches of Mallee is extensive, and they are soon succeeded by grassland.

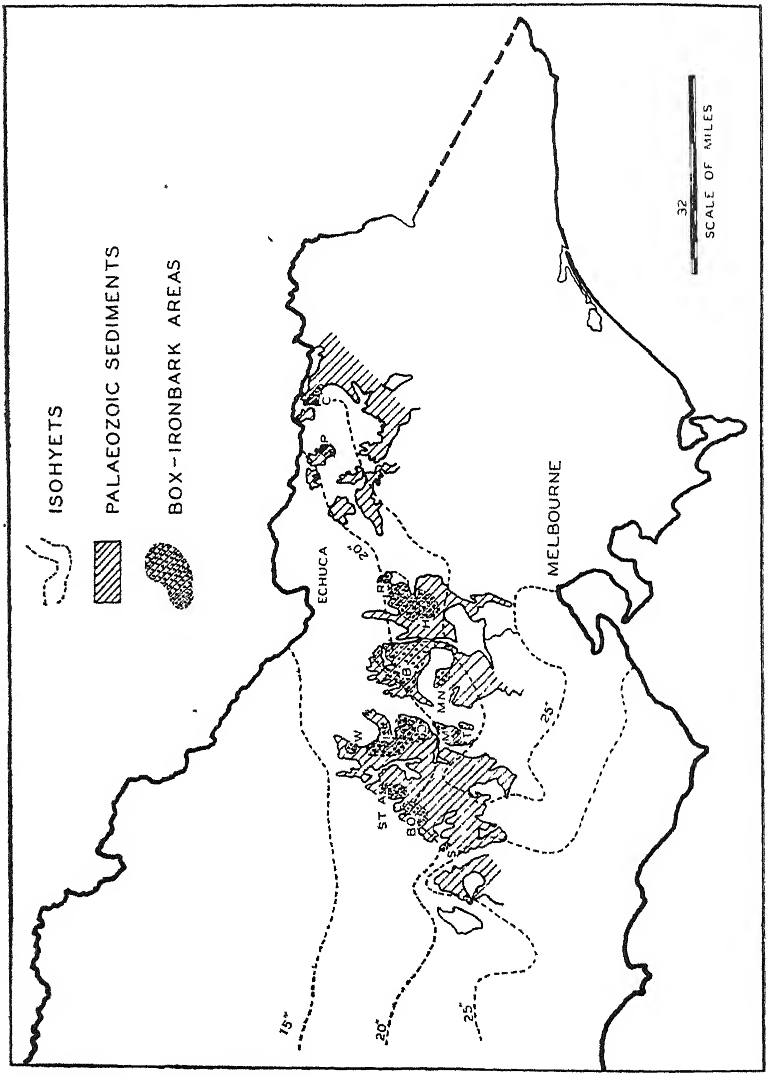


Fig 1.—Distribution of Box-Ironbark Areas in Victoria. B = Bendigo, Bo = Bolangum, C = Chiltern, D = Dunolly, H = Heathcote, I = Inglewood, M = Maryborough, Mn = Maldon, P = Peechelba, R = Rushworth, S = Stawell, St. A. = St. Arnaud, T = Talbot, W = Wedderburn.

The distribution of rainfall over the year is distinctly of a winter type, but this is by no means pronounced. In the southern half of the State an even distribution of rain occurs, as shown by Melbourne records. In fig 2 is shown a graph of the monthly distribution for Bendigo, which is typical of the remaining Stations. The distribution is also given for Melbourne for comparison.

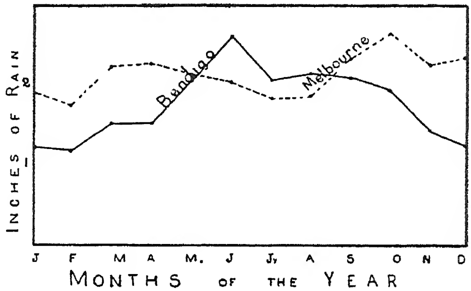


FIG 2.—Monthly Distribution of Rainfall for Bendigo and Melbourne.

The actual and relative amounts of rainfall received during the six summer months, October to March, and the six winter months, are given in Table II. for selected Stations, which may be regarded as typical of the remainder. Rainfall is approximately half as much again during the winter as in the summer months.

TABLE II.—RATIO OF THE RAINFALL OF THE SIX SUMMER TO THE SIX WINTER MONTHS.

| Station. | Rainfall for Six Months. | | Ratio. |
|---|---|---|---|
| | October–March. | April–September. | |
| Bendigo | 8·64 | 12·60 | 1 . 1·46 |
| Maryborough | 8·18 | 12·16 | 1 . 1·49 |
| St. Arnaud | 7·16 | 12·20 | 1  1·70 |
| Stawell | 8·05 | 13·22 | 1 : 1·64 |

Besides the annual amount of rain and its yearly distribution, the regularity with which it is received year by year is also a factor in the development and character of the vegetation. In Table III. are given the Coefficients of Variability for selected Stations. These values represent a reasonable degree of reliability when compared with a 34.5 per cent. variability for Mildura and 12.3 per cent. for Portland.

TABLE III.—COEFFICIENT OF VARIABILITY OF RAINFALL IN BOX-IRONBARK AREAS.

| Station. | Co-efficient of Variability |
|---|---|
| | % |
| Bendigo | 24·5 |
| Maryborough | 22·33 |
| St. Arnaud | 21·71 |
| Stawell | 21.43 |

TEMPERATURE.

Temperature must also be considered from two standpoints, Average Annual Temperature and the Monthly Distribution.

As with the case of rainfall, the temperatures of the various Stations are closely similar. In Table IV. are given the annual temperature of the same stations shown in Table III.

TABLE IV.—MEAN ANNUAL TEMPERATURES OF SELECTED STATIONS IN BOX-IRONBARK AREAS.

| Station. | Annual Temperature. |
|---|---|
| Bendigo | 59·0°F |
| Maryborough | 57·4°F |
| St. Arnaud | 58·1°F |
| Stawell | 57·9°F |

The monthly distribution of temperature indicates that north of the Divide the climate is becoming decidedly continental. Several of the cooler months of Stations in the Box-Ironbark areas are colder than those of Stations along the coast, and in fig. 3 are given the graphs of Bendigo and Lorne for comparison. Lorne is selected because it is not far from Airey's Inlet where Red Ironbark occurs. The six winter months of Melbourne are also warmer than the same six months of Bendigo. However, the summer months of the latter are very much warmer. The graph for Bendigo is typical of the other stations.

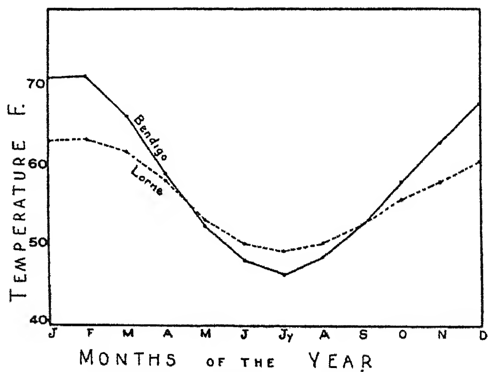


FIG. 3.—Monthly Distribution of Temperature for Bendigo and Lorne.

The highest temperatures occur during February, and this is the same for all other stations, while the lowest are in July. This makes the graph asymmetric since there are only five months from the peak of summer to the trough of winter. The range of monthly temperatures for Bendigo is 25.1°F., and the lowest range for Box-Ironbark is 22.7°F. Lorne having an oceanic climate has a range of only 15°F.

EVAPORATION.

There are no Stations recording evaporation near any of the Box-Ironbark forests, and the values given in Table V. have been calculated from other weather data. These indicate that the average annual evaporation lies approximately between 45 and 50 inches.

TABLE V.—ANNUAL EVAPORATION IN BOX-IRONBARK FORESTS.

| Station. | Annual Evaporation (calculated). |
|---|---|
| Bendigo .. .. .. . .. .. . | 50·53 inches |
| Maryborough .. .. .. .. .. .. .. | 45·95 ,, |
| St. Arnaud .. .. .. . .. .. . | 50·80 ,, |
| Stawell .. . .. .. .. . .. | 46·44 ,, |

The monthly distribution of evaporation is naturally affected by the continental character of the temperature range. In fig. 4 is given the monthly distribution of evaporation for Bendigo.

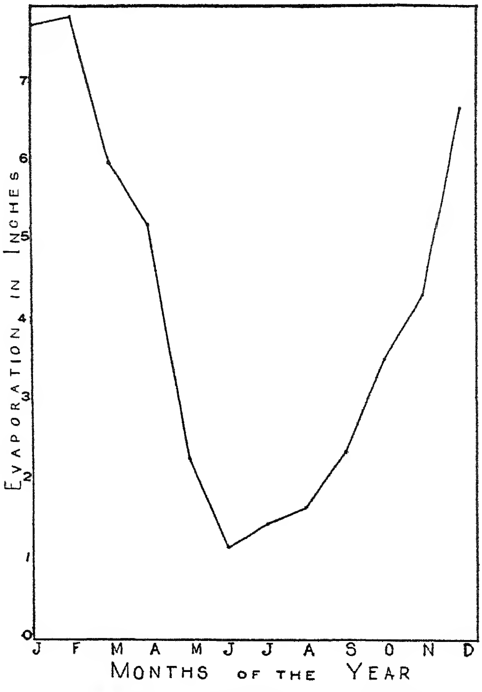


FIG. 4.—**Monthly Distribution of Evaporation for Bendigo.**

### Summary of Climate.

The general features of the climate in the Box-Ironbark areas agree fairly well with the chief characteristics of that of the Mediterranean, as outlined by Kendrew (1937). Kendrew observes that most of the rainfall occurs in the winter half of the year and that in summer there are more or less drought conditions, which do not last more than three months. As will be shown later there is an absence of floral activity for about three months of the year. Kendrew also says that the winters are mild, the coldest month having a mean temperature above 40°F. Of all the Stations in the Box-Ironbark areas where temperature records are kept, the lowest monthly mean is 45.1°F. at Maldon; in summer the warmest monthly mean exceeds 70°F. This also agrees reasonably well with the January temperatures of all the Box-Ironbark stations. For Box-Ironbark the lowest January mean temperature, the month in our climate corresponding to July in the northern hemisphere, is 67.5°F. at Maldon. In all cases where temperature is recorded February is the warmest month.

The third characteristic is the clear, sunny, almost cloudless sky during summer. This is a feature of our areas north of the Divide and requires no comment. Kendrew regards the Olive Tree as one of the most characteristic of the Mediterranean vegetation. This has evergreen leathery leaves, a feature characteristic of our eucalypts.

These climatic conditions are reflected in the vegetative and floral activity of the Box-Ironbark association. Plant life is dormant for about three months corresponding to the three drought months indicated by Kendrew. After the drought is over the lower temperatures retard, but do not inhibit, plant activity. In the closely allied Red Box-Red Stringybark association of the south, as shown by the author in 1937, the curve of flowering commences to rise from May; but in the Box-Ironbark there is little activity until after June. In other associations of the south, as shown by the author in 1933 and 1936, the curve of flowering is the same as in Red Box-Red Stringybark. In the southern examples of Red Box-Red Stringybark both August and September are very active months, but in the Box-Ironbark the amount of flowering in August and September is little more than in July. In both associations, the peak of flowering is in October with a very rapid fall to December, which in both instances is due to rising temperatures and declining moisture. In the climatic conditions at Bendigo, as with the other occurrences of Box-Ironbark, the length of the period of the year favourable to plant

activity is more restricted than in the associations given south of the Divide. In fig. 5 is shown the distribution of flowering over the year for Bendigo.

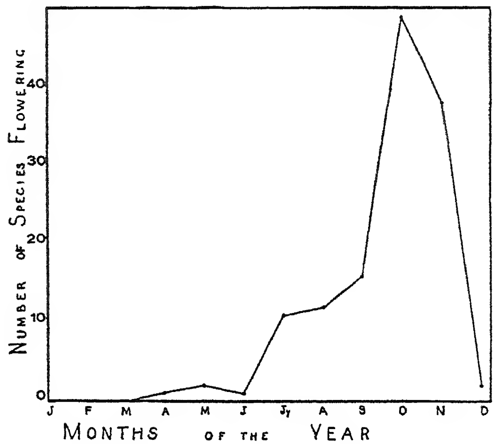


FIG. 5.—Monthly Distribution of Flowering Box-Ironbark Association.

## GEOLOGY.

All the Box-Ironbark forests are situated to the north of the Central Highlands, the lower limit of these being taken for botanical purposes at 1,000 feet. The greatest elevation of any of the Stations for which climatic data were given is 818 feet, at Talbot, which is the most southerly point of the Box-Ironbark forests. Here they are limited both on the east and on the west by the long stretches of the newer basalt which connects with the basalt plains south of the Divide. The southward extension is prevented by the basalt so that the climatic limit has not been reached.

The contour of the land where the various examples of this association occur is never very steep, but fairly gentle. Hence, neither the degree nor the aspect of the slope is a factor influencing the vegetation of the area.

It has already been mentioned that the Box-Ironbark forests are discontinuous, and that they are separated from one another by areas of natural grassland or savannah. In the long stretch of country through which the various stands of Box-Ironbark are situated there are four geological formations of considerable

extent, namely Granite, Ordovician, Newer Basalt and Post-Tertiary Sediments. There is a broad belt of Newer Basalt running up from the south, nearly across the Western Highlands which is strictly grassland; the surface is flat and the soil is well developed. The Post-Tertiary Sediments belong to the Murray River system, and although they are essentially grassland, they vary from treeless plain to Savannah forest. West of Stawell there is a large area of Post-Tertiary deposits which is a continuation of the Wimmera grasslands, but which is dominated by a forest of Grey Box and White Ironbark. There is no Red Ironbark present, and therefore this area has not been included in fig. 1. Both of the first two mentioned species pass out into the grassland to form Savannah. Wherever the trees steadily increase in density, the character of the grass floor is not lost and when the land is cleared good grassland results. These Savannah forest areas may best be regarded as a compromise between climatic and soil influences. This type of vegetation was extensive where the plains join the foothills of the Divide.

The Granite breaks down into a gravelly porous soil which, according to contour, bears two different types of vegetation. To the east of Chiltern it is covered with Red Box and Red Stringybark, with a strong admixture of *Callitris calcarata*. This is a very special variation of the Red Box-Red Stringybark association so common in the State. Granite immediately adjoins the Peechelba stand, but this is also clothed with Red Box-Red Stringybark. In both of these areas the country is sharply contoured and, taken generally, mountains are covered with forest.

South of Bendigo at Big Hill where the granite commences there is a sudden termination of the Box-Ironbark association. The granite country is generally grassland and gently undulating, with scattering trees, among which is River Red Gum *Eucalyptus rostrata*. East of Castlemaine where it rises into Mount Alexander it is forest clad. South of the granite outcrop the Box-Ironbark again appears from Maldon to Castlemaine, so that the granite here has this association on both sides of it.

The fourth geological formation, the Palaeozoic Sedimentary rocks, is the home of the Box-Ironbark. Not every outcrop, however, bears this forest, for it too may carry open forest, with a grass floor where it has a very flat contour and adjoins grassland. It is difficult to speak of soil in the ordinary usage of the word, for but little exists. The rock lies at or near the surface, and therefore the roots of the plants must pass into the disintegrated rock or even between the strata. At the bottom of the

slopes in hilly or undulating country, there is an accumulation of clay, and here one may speak of soil in the ordinary sense. The upper slopes may be very stony. In places quartz lies freely on the surface and these areas can be practically destitute of lower vegetation.

## Composition.

One of the remarkable features of the Box-Ironbark association is the large number of species that are very rare or infrequent, but which are common in associations having a higher rainfall and a lower temperature. Many plants common south of the Divide as *Leucopogon virgatus, Daviesia ulicina, Dillwynia floribunda, Correa rubra, Leptospermum myrsinoides, Lomandra filiformis, Drosera Menziesii, Plantago varia* and *Craspedia uniflora* are in this association, but are sparsely represented, and this is due to the fact that they are reaching their limits of distribution or that conditions are very unfavourable for their free development.

Other species which are common in other associations, as well as here, represent those which have a wide amplitude as regards habitat factors. These ubiquitous species have been designated as ecological wides, Patton (1930). Such species, being found in a number of associations, are said to possess a very low degree of fidelity to any particular one. Among these are *Poa caespitosa, Dianella revoluta, Dichopogon strictus, Glossodia major, Ranunculus lappaceus, Tetratheca ciliata, Wahlenbergia gracilis* and *Microseris scapigera*. Such species, existing as they do under widely differing conditions, may be expected to show a great deal of variation, and this is the case with *Poa caespitosa* and *Wahlenbergia gracilis* but not with others. The question arises as to whether these different forms are actual species and not varieties. The separate forms, however, may be ecotypes.

Those species, which very definitely distinguish an association, are known as Characteristic Species. Besides the three species of Eucalyptus there are others which are equally distinctive. These characteristic species may be confined to a particular association and therefore show a high degree of fidelity to it. On the other hand, a species may be equally well developed in another association and there also characteristic of the second. In such instances as the latter the species show a lower degree of fidelity. Thus *Acacia acinacea* and *A. diffusa* are characteristic both of Box-Ironbark and Red Box-Red Stringybark associations. On the other hand *A. pycnantha* (Golden Wattle), is perhaps the most characteristic species and shows a high degree of fidelity. Other characteristic species are *Grevillea alpina, G. ilicifolia, Brachyloma daphnoides* and *Eriostemon obovalis.*

Another feature of the vegetation, but by no means a obvious one, is the number of very small annuals that occur. Such small plants are best spoken of as Minutae. The presence or absence of these, their abundance, and the degree of development are controlled by the weather in any particular year. So small are many of these plants that as many as four species have been found in a single square inch. Among the Minutae are *Levenhookia dubia, Toxanthus Muelleri, Millotia tenuifolia* and *Helipterum demissum.*

In the Box-Ironbark Association there is a good representation of the most prolific families and genera of Victoria. Of the ten most prolific families given by Patton (1935), no less than eight are present. The two families which are absent have rather specialized habitats, and therefore their absence occasions no surprise. Of the fifteen genera with the greatest number of species in Victoria, twelve are present. The absence of Olearia is a matter of interest since this genus is abundantly present from the wettest to the driest parts of the State, so that apart from this genus, the flora of the Box-Ironbark association is therefore quite representative of the State.

The family Myrtaceae provides the three dominants of the association, but other than these it is poorly represented. *Leptospermum myrsinoides,* which is very rare, is the only other representative. At Maryborough *Calytrix tetragona* is locally abundant. The family Epacridaceae is very well represented by no less than five genera and six species; only one genus Leucopogon, however, has more than one species present. Of the six species of this family only one, *Brachyloma daphnoides,* is abundantly present. All species have small, thick, leathery leaves.

There is only one genus, Grevillea, of Proteaceae and this has two species present. *G. alpina* has usually a red flower, but a white variety regularly occurs, which is said to be the only form present at Rushworth. The genus Acacia is the most important member of Leguminosae. At the type area there are five species present, and three of these *A. acinacea, A. armata,* and *A. vomeriformis* possess very similar characters. The inflorescence is a globular head and the phyllode is small and uninerved.

To the east of Bendigo, in the Box-Ironbark forests as well as in other areas, two other closely related species *A. aspera* and *A. obliqua* occur, while to the north in the Whipstick Mallee are two more closely related species, *A. brachybotrya* and *A. lineata,* the

latter being recorded by Patton in (1924). Six of these species may be regarded as being derived from the simple common form, *A. acinacea,* in which the phyllode is symmetrical, or almost so, narrow and about half an inch long. *A. armata* has an undulate phyllode, and the stipules are developed into spines. In *A. aspera* the phyllode is slightly undulate and it is covered with glandular hairs which make it very rough. The phyllode of *A. brachybotrya* is generally slightly longer than in *A. acinacea* and broader in proportion to its length. The surface is covered with soft pubesence, making it very glaucous. In the remaining three, asymmetry which is more or less present in the others, becomes marked. In *A. vomeriformis* the asymmetry takes the form of one side of the phyllode being developed into a triangular lobe at the base, while in *A. obliqua* one side is shortened. The asymmetry in *A. lineata* is caused by one side of the phyllode failing to develop thus bringing the midrib near to one edge. The suggested relationship of all these species is given in fig. 6.

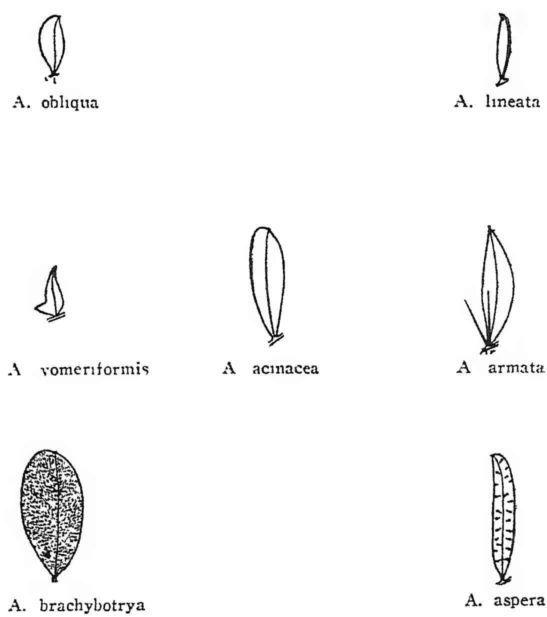


FIG. 6.—Relationship of species of Acacia with small Uninerved Phyllodes (natural size).

The species given in the following list have all been collected at Bendigo, between Kangaroo Flat and Big Hill, and for a distance about 2 miles west of the Highway. This area is taken as the type of the Association. Species found in other parts of the Bendigo district are not given.

## MONOCOTYLEDONAE.

GRAMINEAE—
*Stipa Drummondii*
*S. scabra*
*S. mollis*
*Dichelachne crinita*
*D. sciurea*
*Danthonia geniculata*
*D. pallida*
*D. semiannularis*
*Aira caryophyllea*
*Poa caespitosa*

LILIACEAE—
*Burchardia umbellata*
*Anguillaria dioica*
*Bulbine bulbosa*
*Thysanotus Patersonii*
*Dichopogon strictus*
*Tricoryne elatior*
*Dianella revoluta*
*Lomandra filiformis*

AMARYLLIDACEAE—
*Hypoxis glabella*

ORCHIDACEAE—
*Calochilus Robertsonii*
*Cyrtostylis reniformis*
*Caladenia carnea*
*C. coerulea*
*C. praecox*
*C. testacea*
*Glossodia major*
*Diuris maculata*
*Pterostylis cycnocephala*
*P. longifolia*
*P. nana*
*P. nutans*
*P. parviflora.*

## DICOTYLEDONAE

### ARCHICHLAMYDEAE.

PROTEACEAE—
*Grevillea alpina*
*G. ilicifolia*

SANTALACEAE—
*Exocarpus cupressiformis*

CHENOPODIACEAE—
*Rhagodia nutans*

CARYOPHYLLACEAE—
*Sagina apetala*

RANUNCULACEAE—
*Ranunculus lappaceus*
*R. parviflorus*

LAURACEAE—
*Cassytha glabella*

DROSERACEAE—
*Drosera auriculata*
*D. Menziesii*
*D. peltata*
*D. Whittakeri*

CRASSULACEAE—
*Crassula Sieberiana*
*C. micrantha*

PITTOSPORACEAE—
*Bursaria spinosa*
*Cheiranthera linearis*

ROSACEAE—
*Acaena ovina*

LEGUMINOSAE—
*Acacia acinacea*
*A. armata*
*A. aspera*
*A. diffusa*

LEGUMINOSAE—*continued*
*A. vomeriformis*
*A. pycnantha*
*Daviesia ulicina*
*Pultenaea largiflorens*
*P. laxiflora*
*Dillwynia ericifolia*
*D. floribunda*
*Hardenbergia monophylla*

GERANIACEAE—
*Geranium pilosum*
*Pelargonium Rodneyanum*

OXALIDACEAE—
*Oxalis corniculatus*

RUTACEAE—
*Eriostemon obovalis*

TREMANDACEAE—
*Tetratheca ciliata*

DILLENIACEAE—
*Hibbertia acicularis*
*H. sericea*

THYMELAEACEAE—
*Pimelea humilis*
*P. involucrata*

MYRTACEAE—
*Eucalyptus Sideroxylon*
*E. leucoxylon*
*E. hemiphloia*
*E. melliodora*
*E. macrorrhyncha*
*E. polyanthemos*
*Leptospermum myrsinoides*

UMBELLIFERAE—
*Daucus glochidiatus*
*Hydrocotyle capillaris*
*H. laxiflora.*

METACHLAMYDEAE.

EPACRIDACEAE—
*Astroloma humifusum*
*Melichrus urceolatus*
*Leucopogon virgatus*
*L. rufus*
*Acrotriche serrulata*
*Brachyloma daphnoides*

GENTIANACEAE—
*Sebaea ovata*

SCROPHULARIACEAE—
*Veronica plebeia*

PLANTAGINACEAE—
*Plantago varia*

CAMPANULACEAE—
*Wahlenbergia gracilis*

GOODENIACEAE—
*Goodenia geniculata*
*Brunonia australis*

STYLIDIACEAE—
*Stylidium graminifolium*
*Levenhookia dubia*

COMPOSITAE—
*Brachycome perpusilla*
*Craspedia uniflora*
*Toxanthus Muelleri*
*Rutidosis multiflora*
*Millotia tenuifolia*
*Leptorhynchus squamatus*
*Helichrysum bracteatum*
*H obcordatum*
*H. semipapposum*
*Helipterum australe*
*H. demissum*
*Gnaphalium indutum*
*Erechthites quadridentata*
*Microseris scapigera*

## Structure.

The structure of the association is simple. The trees stand well apart from one another (Plate 1) so that their crowns do not meet. Thus ample light reaches the forest floor, but the entry of light is further assisted by the habits of the trees themselves. Grey Box is a fairly tall tree commonly with the two main branches forming a capital Y (Plate 1). The foliage is restricted to the ends of the ultimate branchlets and is not dense (Plate 1). Such a habit enables a great amount of light to filter through the crown and reach the forest floor. White Ironbark has no distinctive habit of branching, but the crown is not very dense and this enables light to pass through.

Red Ironbark, however, has an entirely different habit. Typically, the lateral branches of young to middle-aged trees are short and emerge at a very wide angle. Old trees become very scraggy. The foliage is borne right along the trunk (Plate 1), so that in an open grown specimen the tree presents the form of a narrow cylinder. Thus very little shade is cast. Both Grey Box and Red Ironbark, by their habit of growth, are favourable for the growth of an abundant shrub and ground flora, but these lower strata, however, are not strongly developed. There is no second stratum of trees, but occasionally isolated specimens of *Exocarpus cupressiformis* are present. At times *Acacia pycnantha* is abundant and forms a very open tall shrub or very small tree stratum. When in full bloom the golden flowers are strikingly contrasted against the dark stems and dull green crowns of the dominant trees. *A. diffusa* grows nearly as tall as the Golden Wattle, but is not so plentiful. Even when these two Acacias are present there is still an abundance of light reaching the forest floor. The degree of development of the medium shrub and undershrub strata varies widely. At times, the surface of the soil is quite bare even though the trees are spaced widely enough apart for full light to reach the ground. In such cases quartz is frequently very

abundant at the surface. In contrast to this, the medium shrub stratum may be strongly developed and give the soil complete or almost complete cover. The members of this layer are the characteristic species *Brachyoma daphnoides* and *Grevillea alpina.* This stratum is particularly well developed on rising stony ground where Red Ironbark predominates. On the lower slopes, Grey Box may be in a pure stand, and here the soil has a high percentage of clay. In such places the two characteristic shrubs are generally absent. The shrub stratum is therefore very discontinuous. Of the undershrubs, *Hibbertia acicularis* forms very dense bushes which are covered with a brilliant mass of yellow flowers in spring. This undershrub story is also very incomplete and therefore there is a large percentage of the soil exposed to the weather. Although there are a number of grass species present, none are abundant, and, therefore, do not assist in forming a soil cover.

Geophytes are fairly common, particularly in the spring, but they do not have much influence as regards soil cover. Two orchids *Glossodia major* and *Caladenia testacea* are very abundant in some years and give tinges of colour to the landscape. The forest then is very open and the ground cover very incomplete. The protection of the soil is further decreased by the small ericoid leathery leaves of the shrub strata, with the exception of *Grevillea ilicifolia.* Associated with the poor cover of the soil is the slowness of decay of debris from the trees, the amount of humus reaching the soil is therefore small.

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## Description of Plate.

PLATE I.

Fig. 1. Box-Ironbark Forest with absence of lower strata, soil very gravelly.
Fig. 2. Box-Ironbark Forest with lower strata well developed, consisting partly of re-growth of eucalypts.
Fig. 3. Red Ironbark, Eucalyptus sideroxylon.
Fig 4. Bark of Red Ironbark.
Fig. 5. Bark of Grey Box.
Fig. 6. Grey Box, E. hemiphloia.

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[PROC. ROY. SOC. VICTORIA 56 (N.S.), PT. I, 1944.]

# ART. IV.—*Superficial Sand Deposits between Brighton and Frankston, Victoria.*

By SYLVIA WHINCUP, B.Sc.

[Read 8th July, 1943; issued separately 1st August, 1944.]


## Abstract.

Four types of sand formations are described (1) Longitudinal dune ridges which occur with great regularity in the Brighton area; (2) irregular barchan dunes in the Frankston area; (3) coastal ridges in the low-lying area between Mordialloc and Frankston; (4) lunette ridges believed to have been formed on the northern sides of swamps between Brighton and Frankston.

The mode of formation of the deposits is deduced from their shape, orientation and extent, and the stratification and degree of sorting of the sand, while the heavy minerals present and the roundness of grains give an indication of the origin of the sand. Factors which have influenced the physiography of the area are: tectonic movements, forming the low-lying area now occupied by the swamp; climatic changes, leading to formation of dunes and their later preservation by vegetation; and changes in sea level, which have caused the formation of three successive coastal ridges, two of which are very close together behind the present coastline, and one further inland forming the boundary between Carrum Swamp and Dandenong Swamp.


## Introduction.

The present investigation has been carried out in an attempt to elucidate the nature and origin of the various types of superficial sand ridges that occur between Brighton and Frankston. The sand ridges in the Brighton district were mapped from aerial photographs which covered the area as far east as Edithvale Road. The position of ridges and depressions could be determined reasonably accurately with the aid of a stereoscope, and most of the ridges were then examined in the field. In the areas not covered by aerial photographs, the boundaries between sand ridges and alluvial flats were mapped on the ground. There is a marked difference in the vegetation cover of the sand ridges and the alluvial flats, which is most noticeable in the south-eastern part of the area, where settlement has not been so close as further north. Here most of the sandy areas have been left uncleared. whereas the alluvial flats are used extensively for agriculture. The most striking feature of the natural vegetation is the presence of bracken on any low sandy area, which may otherwise be almost indistinguishable from the alluvial flats, on which bracken is never found.

## Physiography.

On physiographic grounds, the area described is divisible into north-west, central and south-east sectors.

### The North-Western Sector.

This includes the coastal plain of the Brighton district, which extends inland for 4-5 miles towards the low foothills of the Eastern Highlands along the Gippsland-road. In the south, it terminates along the northern edge of the low-lying swampy areas which comprise the central sector (see below). Between Brighton and Mordialloc, there is a regular series of long, low, parallel sand ridges with intervening swampy depressions, all of which have a north-westerly trend. They have been described by Hart (1913), who suggested that the formation of regular, parallel valleys was due to "lines of easy erosion" in the Tertiary rocks over which the present drainage system developed.

The ridges, however, have not been previously studied in detail. Hills (1940A) states that "sand ridges were formed on some of the sandy coastal plains, as for instance in the Moorabbin-Highett district" during periods of relative aridity in recent times, but the extent and remarkable regularity of the ridges and shallow depressions, which may be seen on the map (fig. 1) have not been generally realized.

Owing to their parallelism to the present coast, it might be suggested that the ridges are old beach ridges left behind during a retreat of the sea. No shells, waterworn pebbles or other evidence suggestive of beach deposits, however, have been found in association with these ridges, and it is considered, on evidence that will be discussed below, that they are of aeolian origin.

The sand ridges are symmetrical in cross-section and have relatively flat tops. Because of their age, however, any minor morphological details such as a sharp crest, or slight variations in the slopes on either side that might once have existed, may have been modified by erosion. In their straightness and regular parallel arrangement they resemble longitudinal dune ridges, such as have been described by Madigan in Central Australia (1936), and, although the Brighton ridges are broader and much closer together than the Central Australian ones, it seems probable that they were formed under similar conditions and are actually longitudinal dunes. Further to the east on the other side of the low divide referred to as the Cheltenham Axis by Hart (1913), the ridges become shorter and less regular, although the same north-westerly trend of the country is still apparent. The drainage here is in a south-easterly direction towards Carrum Swamp.

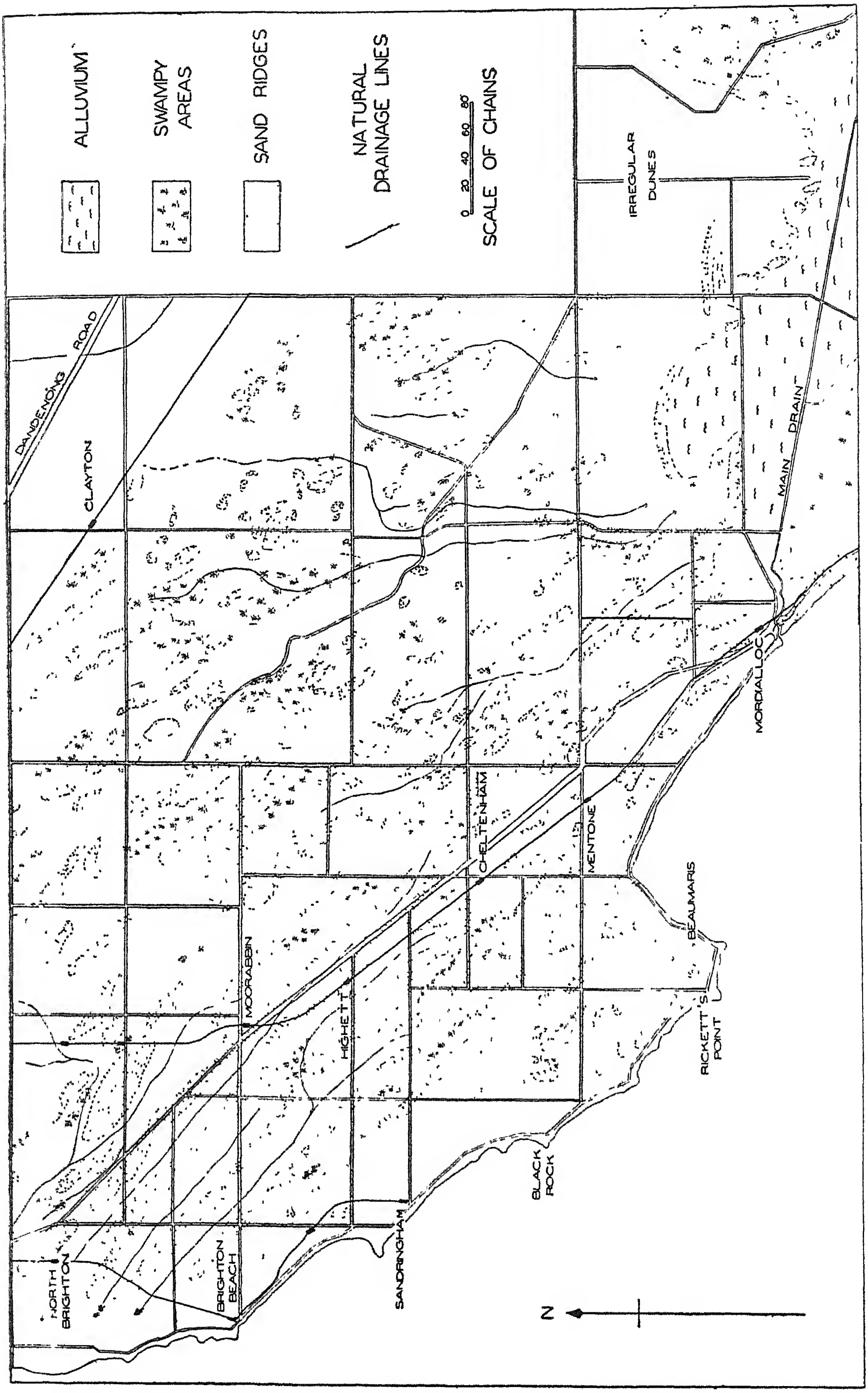


Fig. 1.—Map of Sand Ridges on the Coastal Plain between Brighton and Mordialloc.

### South-Eastern Sector.

This part of the area includes the country between Frankston, Carrum Downs and Cranbourne, over which extensive sand deposits are also found. In this sector, the land is higher and not as flat as in the Brighton district, and there is a marked difference in the external form of the sand ridges compared with those in the north-western sector.

Instead of the parallel ridges and valleys found in the north-west, individual sand hills are irregularly dispersed and do not cover the whole of the area. These sand hills are so crowded together and are so irregular in height and size, that their true form is hard to distinguish. They resemble barchans in that most of them are slightly curved and have a steeper face on the concave side, and will be referred to as such in this discussion. At the bottom of the steeper slopes, swampy areas, in which the vegetation is very thick in contrast with the heathy type of vegetation growing on the sand hills themselves, commonly occur.

The depth of sand in these deposits is much greater than in the longitudinal ridges in the north-west, 80-90 feet of sand being exposed in many of the pits along the Frankston-Cranbourne road.

### Central Sector.

Between the above two sectors in which sand formations are widespread, is the flat and relatively low-lying area occupied by the Carrum and Dandenong Swamps. Carrum Swamp is separated from the sea by a continuous line of sand ridges parallel to and just behind the present coastline. Further inland, about 1½ miles from the coast at its greatest distance, a similar curved sand ridge forms the boundary between Carrum Swamp and Dandenong Swamp (see fig. 2). This ridge, along which Wells'-road runs, is more or less continuous from Mordialloc to Frankston, and has been referred to as Wells'-road Ridge (Hills, 1940B). The whole of the flat low-lying area extending inland from Wells'-road for about 5 miles will be referred to as the Dandenong Swamp.

*Coastal Ridges.*—Along the sweeping curve of the coastline between Mordialloc and Frankston, there are no cliffs such as are found to the north and south, the coast being composed entirely of sand. About 3 chains inland is a continuous ridge of sand of fairly uniform height, along which the Melbourne-Frankston railway line has been constructed. Between Mordialloc and Carrum there is only a single main ridge, behind which is a low sandy area descending towards the edge of Carrum Swamp. This ridge becomes wider towards Carrum and splits up into

two parallel ridges, between which Kananook Creek flows until it breaks through to the sea at Frankston. A diagrammatic cross-section through this part of the coast is shown in fig. 4.

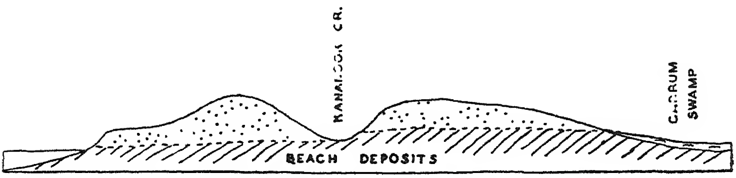


FIG. 4.—Diagrammatic Section through the Coastal Ridges at Seaford. (Not drawn to scale.)

As will be seen in the discussion of their lithology, these ridges are composed of wind-blown sand resting on beach deposits, and they are, therefore, " dune ridges " as defined by Johnson (1919).

*Wells'-road Ridge.*—This ridge is not as high nor as continuous as the one close to the beach, but it can be followed with some gaps in a curved line from the corner of Edithvale-road and Wells'-road until it joins the coastal ridges just north of Frankston. In most parts where the ridge is very prominent, its south-eastern or seaward edge is more regular and better defined than the landward edge.

*Alluvial Flats.*—The Carrum Swamp, between Wells'-road and the coastal ridges, has already been described (Hills, 1940B). Although part of it is now permanently under water near Seaford, the general level of the surface, before sinking took place on cultivation, has been stated to have been 4½ feet above sea level.

The Dandenong Swamp is higher than Carrum Swamp, but just as flat. All the water entering the area from the Dandenong and Eumemmerring Creeks is now confined to drains, and the area is no longer swampy. The two most important drains are the Main Drain, which supplies Mordialloc Creek, and a secondary drain which enters the sea through an artificial cut in the coastal sand ridges at Carrum.

Sand ridges form the boundaries of Dandenong Swamp in the north and the south-east (fig. 2), but towards the north-east, the land gradually rises to where Tertiary rocks outcrop at the surface in the neighbourhood of Lyndhurst. The country here becomes undulating, and the Tertiary rocks are in places covered by wind-blown sand.

The south-eastern boundary of the alluvial flats runs approximately north-east from Frankston along the main Frankston-Dandenong road as far as Carrum Downs, and then continues east towards Cranbourne. Thus, for part of the way, it follows

a north-easterly extension of Selwyn's Fault (Hills, 1940A, p. 160). Along the edge of the swamp, the sand hills are very low and irregular, but they increase in height fairly rapidly away from the alluvial flats, not so much because of increasing height

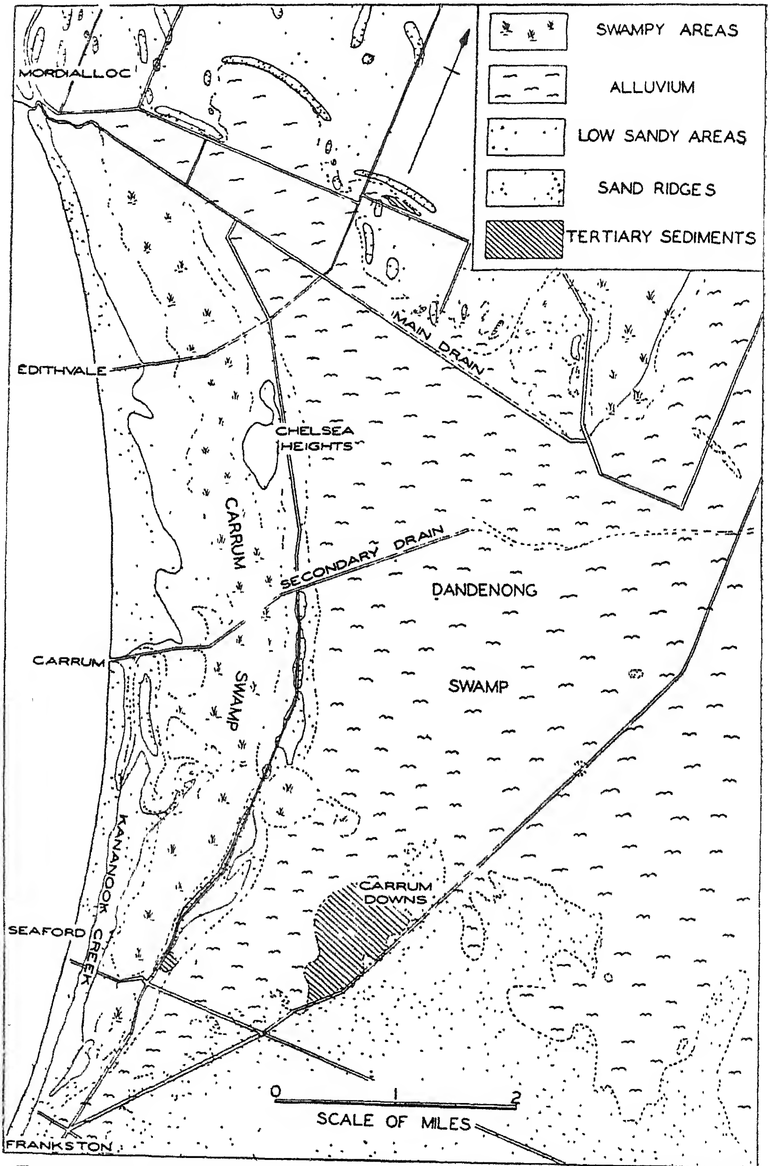


FIG. 2.—Map showing Areas of Sand Ridges and Alluvium between Mordialloc and Frankston.

of sand, but because of the increasing height of the underlying surface of Tertiary and Silurian rocks, which are exposed in many parts of the Frankston district.

Along the northern boundary of Dandenong Swamp, just east of Mordialloc, there are two types of boundary ridges. On the northern side of the Main Drain and east of Edithvale-road are low, irregular, sand ridges, many of which are entirely surrounded by alluvium, and which are probably related to the less regular sand dunes of the north-western sector. The relationship between these sand ridges and the alluvium can be seen in a pit in a low sand ridge near the Edithvale-road. This pit has been continued to a depth level with the surface of the surrounding alluvium, and no change in the nature of the sand can be seen. Below this depth the sand is continuous, indicating that the sand ridge has been partly buried around its base by alluvium. Unlike the south-eastern boundary of the alluvial flats, where the land rises fairly suddenly, the land behind these boundary ridges near the Main Drain rises only gradually towards the north and north-west.

The other ridges along this boundary of the swamp can be seen on the map (fig. 2) mainly between Mordialloc and Edithvale-road, and do not seem to be related to any of the sand ridges already described. They are of uniform height for practically the whole of their length. They trend almost due east and west, are slightly curved with the concave side facing south, and are much longer than any of the other ridges in this part of the area (see fig. 2). The most prominent of these ridges can be seen in a section along the Edithvale-road, just north of Governor-road. The width here is approximately 2 chains and the height approximately 10 feet above the alluvial flats. On the northern side, the land is higher and undulating, with Tertiary rocks outcropping at the surface, which is covered in places by the irregular sand ridges referred to in the North-Western Sector. To the east of these three ridges and on the other side of the Dandenong Creek, there is another relatively long ridge, which is similar in form to those just described, but which could not be closely investigated owing to the fact that it is in a proclaimed military area. As far as could be seen from the road which crosses this ridge, it continues for some distance in an ESE. direction (fig. 2), and both to the north and south of it the land is very flat.

The origin of these ridges is not clear. In their length, uniform height and curvature, they resemble the coastal ridges, and from a consideration of their position it might be suggested that they are remnants of yet another coastline behind Wells'-road. There

is, however, no evidence to show that the coastline has been further inland than Wells'-road since the elevation of the marine Tertiaries. The south-eastern and part of the northern boundary between alluvial flats and the higher sand ridge areas, along which one would expect to find evidence of such a coastline, is very irregular and follows the base of the sand ridges as can be seen from the map (fig. 2). Also, the unbroken uniform height of each of these three sand ridges suggests that they have not been greatly altered by erosion and are probably younger than Wells'-road ridge. It is therefore improbable that they were formed along a former coastline.

On the other hand, these sand ridges cannot be classed with the longitudinal dune ridges further east because of their different orientation and their curvature, nor with the barchan dunes because of their uniform height and greater length in relation to width. A possible explanation of their formation is that they have been built up on the northern sides of the swamps in much the same way as the lunettes described by Hills (1939). An important difference, however, is that, whereas the lunettes in northern Victoria are composed of fine dust particles, which is the only material available in the areas where they are formed, the ridges marginal to the Dandenong Swamp are composed almost entirely of sand, probably derived from the sand ridges further south, and from the sandy alluvium of the swampy areas.

With the exception of parts of the Frankston and Cranbourne areas, where older rocks occur, most of the area dealt with in this paper is underlain by arenaceous or argillaceous Tertiary sediments.

## Lithology.

In order to determine any significant variations in the lithology of sands deposited under different conditions, the following properties of the sand from each type of deposit were investigated.

*Mechanical Composition.*—The degree of sorting of the sand was studied by passing the sample through a series of wire mesh sieves, the size of each mesh being half that of the one above it. The sizes used were: $\frac{1}{8}$ mm., $\frac{1}{4}$ mm., $\frac{1}{2}$ mm., and 1 mm., and, where necessary, 2 mm. and 4 mm. The percentage weights remaining on each sieve and in the pan were then calculated, and the results of all mechanical analyses compared by means of histograms (fig. 3).

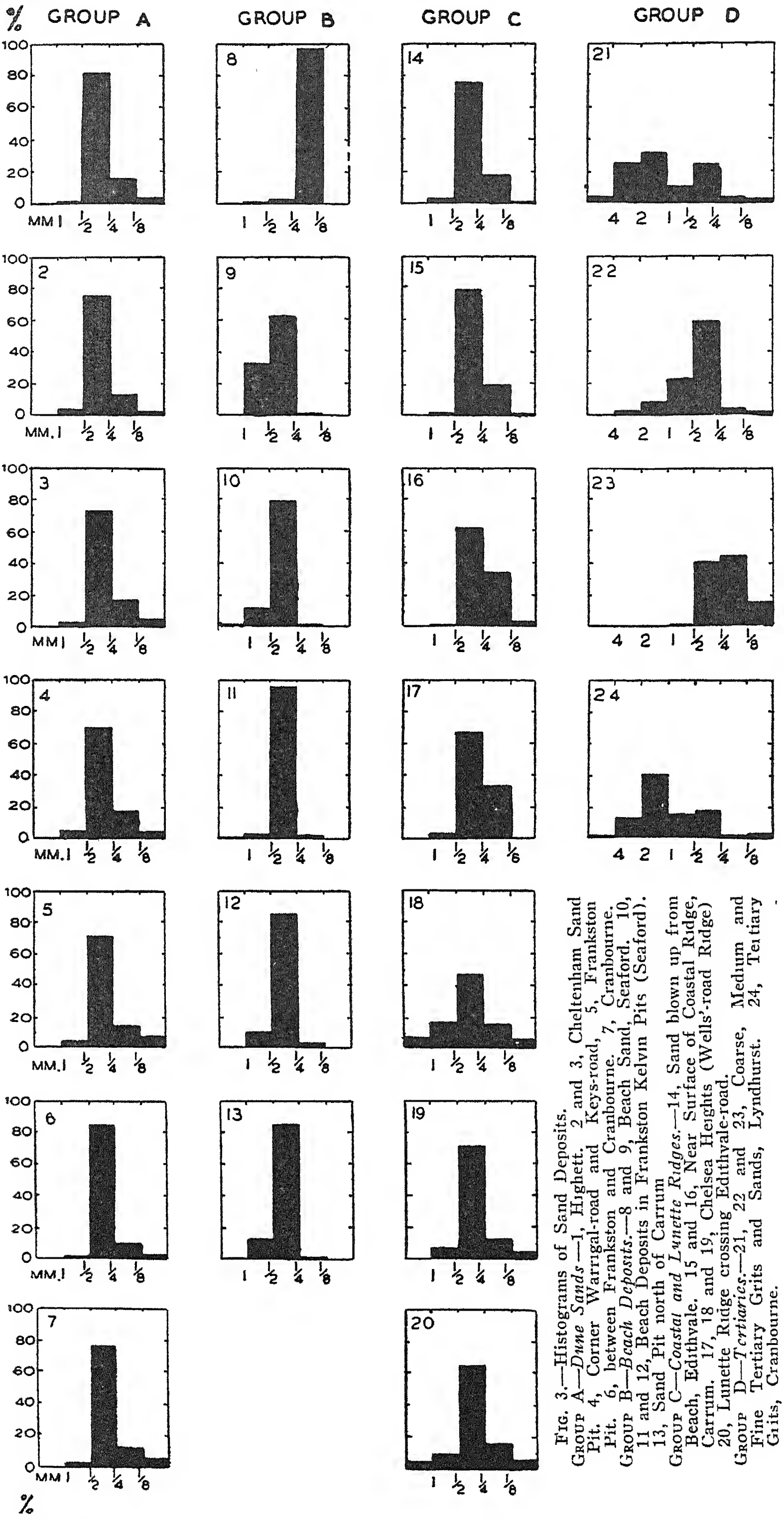


FIG. 3.—Histograms of Sand Deposits.

GROUP A—*Dune Sands*.—1, Highett. 2 and 3, Cheltenham Sand Pit. 4, Corner Warrigal-road and Keys-road. 5, Frankston Pit. 6, between Frankston and Cranbourne. 7, Cranbourne.

GROUP B—*Beach Deposits*.—8 and 9, Beach Sand, Seaford. 10, 11 and 12, Beach Deposits in Frankston Kelvin Pits (Seaford). 13, Sand Pit north of Carrum.

GROUP C—*Coastal and Lunette Ridges*.—14, Sand blown up from Beach, Edithvale. 15 and 16, Near Surface of Coastal Ridge, Carrum. 17, 18 and 19, Chelsea Heights (Wells'-road Ridge) 20, Lunette Ridge crossing Edithvale-road.

GROUP D—*Tertiaries*.—21, 22 and 23, Coarse, Medium and Fine Tertiary Grits and Sands, Lyndhurst. 24, Tertiary Grits, Cranbourne.

When sampling sand, particularly that of beach deposits, for mechanical analysis, it was found necessary to ensure that all the sand was obtained from the one lamina or bed, as frequently two successive laminae are composed of grains of a different size, this depending largely on the conditions prevailing at the time of their deposition. Although each individual lamina may be well sorted, this fact may be obscured if they are not kept separate.

This precaution was not found to be necessary for dune sands, but in these, as in all the sand deposits, if the sand is to be obtained in the same condition as it was deposited, it must be taken from at least 2 or 3 feet below the surface. This is necessary because the surface sand of the A soil horizon has been leached, being now a pale-grey in colour and containing small amounts of humus. Below this horizon, there is generally a narrow zone of dark-brown sand, partly cemented, and below this again the original sand which is usually slightly iron-stained. The depth to which weathering and soil formation have taken place in sand varies from place to place, being greater on flatter areas such as that just north of Carrum, than on steeper and better-drained slopes as on the sides of the Frankston sand ridges.

*Roundness of Grains.*—Sand from each grade of the mechanical analysis was examined in reflected light under a binocular microscope, and the degree of rounding of the grains was noted. No quantitative analysis of the roundness of grains was undertaken as it was not felt that such a detailed study would serve any useful purpose in this investigation.

*Heavy Minerals.*—The heavy mineral assemblages obtained from all sand deposits, as well as from alluvium and Tertiary sediments, were examined and compared (see table of heavy minerals). Separation of the minerals was carried out in bromoform, and for clean sand no preliminary treatment was required. In dealing with samples of material such as alluvium or Tertiary sediments which contain varying amounts of clay, this had first to be removed by washing before a separation in bromoform could be obtained.

*Stratification.*—Because of the loose, unconsolidated nature of many of the sand deposits, stratification, if present, could not always be seen on a fresh surface unless there was some marked change in the sand in succeeding laminae. Normal dune bedding can be seen, however, on the sides of many of the sand pits which have been exposed to weathering for some time.

# Table of Heavy Mineral Assemblages.

| | | | Andalusite | Augite | Biotite | Brookite | Epidote | Hornblende | Ilmenite | Limonite | Leucoxene | Magnetite | Pyrite | Rutile | Tourmaline | Zircon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alluvium | 1 | Carrum Swamp | C | | a | | r | | A | a | r | | | | C | 0 |
| | 2 | Carrum Swamp | r | | | | | | a | r | r | a | V | C | C | C |
| | 3 | Carrum Swamp | r | | | | | | A | | | C | | C | a | C |
| | 4 | Main Drain | V | V | A | | | a | a | C | | C | | | 0 | C |
| | 5 | Main Drain | r | | A | | | a | r | C | | C | | | r | r |
| Coastal Ridges | 6 | Beach Sand | 0 | | r | V | | | a | C | r | V | | r | a | C |
| | 7 | Lunette Ridge | V | | | | | | a | r | | r | | r | C | C |
| | 8 | Seaford | C | | | | | | C | C | | A | | r | r | r |
| | 9 | Carrum | r | | C | | | | a | | r | r | | | C | 0 |
| | 10 | Chelsea Heights | 0 | | | V | | V | A | 0 | r | | | C | C | a |
| | 11 | Chelsea Heights | r | | V | V | r | | a | r | r | | V | 0 | C | C |
| Dune Sand | 12 | Highett | r | | | V | | | A | r | r | r | | 0 | C | C |
| | 13 | Highett | r | | | V | | | A | | C | | | C | C | a |
| | 14 | Cheltenham | V | | | r | | | A | | r | a | | C | C | a |
| | 15 | Cheltenham | 0 | | | | | | A | | | C | | 0 | C | C |
| | 16 | Cranbourne | r | | | V | | V | A | C | r | C | | C | C | C |
| | 17 | Frankston | 0 | | | V | | | A | r | r | C | | r | a | a |
| | 18 | Between Frankston and Cranbourne | r | | | | | | A | C | r | V | | r | C | 0 |
| Tertiary Sands & Grits | 19 | Lyndhurst (Medium) | V | | | r | | | A | | | V | | 0 | 0 | 0 |
| | 20 | Lyndhurst (Fine) | r | | | r | | | A | | r | r | | r | 0 | A |
| | 21 | Cranbourne | 0 | | | | r | | A | | V | r | | 0 | C | A |
| | 22 | Warragul Road | | | | | r | | A | | | | | r | 0 | 0 |

A - very abundant. C - common r - rare.
a - abundant o - occasional. V - very rare.

## Lithological Descriptions.

### Sand Ridges of the North-Western and South-Eastern Sectors.

On comparing histograms of sand collected from many of the pits in the Cheltenham and Moorabbin districts, and also from between Frankston and Cranbourne, it was found that the results were remarkably consistent. These sands are very well sorted (see histograms 1-7). In all samples, over 60 per cent. and in most cases over 70 per cent. of the whole fell into one grade ($\frac{1}{4}$-$\frac{1}{2}$ mm.), this grade being the "chief ingredient" as defined by Udden (1914). Of the remainder, the percentage of the sample with grains smaller than those of the chief ingredient, i.e., Udden's "finer admixtures," was always found to be greater than that of grains coarser than the chief ingredient. It seems to be generally accepted that sands which have a consistently small range in grain size and a high degree of sorting are found only in aeolian dunes and in beach deposits, but the uniform size of the chief ingredient of the sand ($\frac{1}{4}$-$\frac{1}{2}$ mm.) throughout all these deposits in Cheltenham and Frankston districts is typical only of dune sand (Retgers, 1895) Although each sample of beach sand is well sorted, the predominating grain size varies from one lamina to the next.

On examining sand from each grade in reflected light, it was found that the proportion of rounded and sub-rounded grains present increases with increasing size, most grains greater than 1 mm. diameter being rounded. This rounding refers only to the quartz grains, which constitute over 99 per cent. of the sand in all the samples examined. The small percentage of heavy minerals, which are nearly restricted to the smallest grade ($< \frac{1}{8}$ mm. diameter), are mostly well rounded, with a few prismatic and angular grains, although all the quartz grains of similar size are angular.

*Heavy Minerals.*—In all sands collected from the pits referred to above, the most abundant heavy minerals are ilmenite, zircon (round and prismatic), tourmaline (rounded and angular), and rutile. Less common are magnetite, andalusite, limonite and leucoxene (associated with ilmenite). Brookite, hornblende and epidote were recorded from some samples, but not more than one or two grains per slide. In the samples in which these last-named minerals were not recorded, it does not necessarily mean that they are absent from that particular deposit, since it is possible that if it had been practicable to obtain a larger representative sample from that locality, these minerals although rare, would have been recorded.

*Stratification.*—Typical dune bedding with narrow, closely spaced laminae is present in both the longitudinal and barchan sand ridges, and can be seen on weathered surfaces of many of the sand pits. The direction and angle of dip are variable and cross-bedding is common. In all these deposits the grain size is fairly uniform over a considerable vertical range, i e., there is no change in grain size from one lamina to the next, and consequently stratification cannot usually be detected on a fresh surface. In addition to this stratification, a peculiar type of horizontal bedding can be seen in the upper parts of nearly all sand pits in the longitudinal ridges of the Cheltenham district, and along Warrigal-road. At regular intervals, usually about 3 in. to 5 in., narrow bands of relatively hard sand, approximately 2-3 mm. thick, project out slightly from the side of the pit. The sand in these bands is more iron-stained than the average, and also contains small amounts of clay. It is possible that the hard bands represent successive surface layers, in which the cementing material was deposited before additions of sand were made during the growth of the ridges. The iron-stained clay may have been deposited as red dust during dust storms and accompanying mud rains similar to, but more severe than, those which sometimes occur over the area in summer at the present time.

## Coastal Ridges.

The existence of extensive sand pits near Seaford and Carrum made it possible for these deposits to be closely investigated, and from this investigation it has been concluded that the ridges are composed of wind-blown sand and rest on beach deposits which are exposed in the lower parts of the sand pits.

*Beach Deposits Underlying the Ridges.*—The most striking feature of these deposits in contrast to the aeolian sand ridges, is the presence in them of a large number of waterworn pebbles and many marine shells. The pebbles consist mainly of limonite or ferruginous grits derived from the Tertiary rocks, and of metamorphosed sandstone similar to that in the metamorphic aureole of the Mt. Eliza granite. Several rounded fragments of silicified wood comparable with that which occur beneath the Older Basalt at Oliver's Hill, Frankston, were also found.

A shell bed identical in type with those on the present beach is exposed in the sand pit near Seaford about $\frac{1}{4}$ mile from the sea. The bed, which is about 2 inches thick and 1-2 feet wide, consists almost entirely of entire and broken valves of *Amphidesma* mixed with very coarse, well-sorted sand and abundant flakes of biotite. It extends for about 10 yards in a line parallel to the present coastline. Practically all the shells lie with their convex surfaces

uppermost, and it is therefore probable that they were deposited below high-water level. The height of this shell bed above a similar one formed just below high-tide mark on the beach was found to be $3\frac{1}{2}$ feet.

These beach deposits are stratified, and alternate laminae of fine and coarse sand can be seen in many sections through the ridges, particularly along the side of the drain at Carrum, and in the lower 1-2 feet of the shallow pit just north of Carrum, where the sand laminae dip consistently W.S.W. (towards the coastline) at approximately 2°-4°. This pit is not actually in the main sand ridge but in the lower sandy area behind the ridge, and the surface sand is being removed and roughly separated into coarser and finer grades, which are used for building sand and glass making, respectively.

The mechanical composition of sand from some of these laminae is shown in fig. 3, Histograms Nos. 10-13. Neglecting the numerous pebbles present in many samples, the sand was found to be very well sorted with over 80 per cent. in the chief ingredient in most samples. It thus resembles dune sand in the high degree of sorting and the small range in grain size, but there is no record of pebbles ever being found scattered throughout dune sands, and none have been found in the Brighton and Frankston dunes. Another point of difference is that, although the sand from these beach deposits is well sorted, it is not uniform in grain size from bed to bed, that is, instead of the highest percentage of the sample always being found in the grade $\frac{1}{2}$-$\frac{1}{4}$ mm. as in the Cheltenham-Frankston dune sands, the predominating grain size varies in different laminae. For example, in the sand found associated with the shell bed described above, the grade 1-2 mm. forms the chief ingredient, whereas just above this bed the predominating grain size is between $\frac{1}{2}$ and $\frac{1}{4}$ mm.

On examining the histograms of these sands, it can be seen that in most of the samples the percentage of sand coarser than the chief ingredient is slightly higher than that finer than the chief ingredient, and the almost complete absence of grains $< \frac{1}{8}$ mm. in diameter seems to be characteristic. A similar result was obtained for sand collected from the surface of the beach exposed by the retreating tide (Histograms Nos. 8 and 9). Further investigation of sands on the present beach between Mordialloc and Frankston showed that laminae composed of fine sand are, in general, better sorted than those composed of coarse sand, and that very fine or coarse laminae are not as common as those composed of grains between $\frac{1}{4}$ and $\frac{1}{2}$ mm. in diameter. On the beach, the high degree of sorting of the sand can be observed only where the surface has not been disturbed in any way.

The heavy minerals found to be abundant or common in the dune sands are also present in the beach deposits (table of heavy minerals, Nos. 6, 8 and 9). In addition, biotite, which has not been recorded for any of the dune sands other than the coastal dunes, is present in many of the samples from the beach deposits in the sand pits, and from the present beach where it is particularly common at low tide mark. In the light minerals, although quartz is by far the most abundant mineral, shell fragments are also common in sand from the beach, and present, but rare, in sand from the pits.

*The Ridges.*—In contrast with the beach deposits underlying them, the sand forming the coastal ridges is unstratified and contains no shells or pebbles.

In mechanical composition, this sand is similar to dune sand in that the grade $\frac{1}{4}$-$\frac{1}{2}$ mm. is always the chief ingredient and the percentage of finer admixtures is greater than the percentage of coarser admixtures. The degree of sorting, however, varies and, in some samples taken from near the top of the ridge near Carrum, there is a high percentage of grains in both the $\frac{1}{4}$-$\frac{1}{2}$ mm. and $\frac{1}{8}$-$\frac{1}{4}$ mm. grades (Histogram No. 17). This might be expected if the sand forming the ridges had been blown up from the beach in the immediate vicinity, where laminae composed of grains of varying sizes were present. In travelling over such a short distance, there would be little chance of any sorting of the grains.

The heavy minerals found in this wind-blown sand are the same as those found on the beach sand, but biotite, although present, is not as common as in the beach deposits.

Shell fragments also occur but, like biotite, they are not nearly as abundant as on the beach.

*Wells'-road Ridge.*—The mechanical composition of sand from near the surface of this ridge varies from place to place. Some of it is not very well sorted (Histogram No. 18). Some resembles dune sand (Histogram No. 19), and some is similar in composition to the sand near the surface of the coastal dune ridge near Carrum (Histogram No. 17).

In the heavy mineral assemblages, biotite, although very rare, has been found in one sample from Chelsea Heights, but not in the others. As well as the common minerals (ilmenite, zircon, tourmaline, rutile, andalusite), brookite, epidote and hornblende have also been identified in these samples; shell fragments and pebbles are absent.

Considering the absence of shells and pebbles, it seems probable that the ridge is composed entirely of wind-blown sand, and was built up just behind a former coastline, from sand blown up from the beach, which was then situated along the south-east side of the ridge.

*Alluvium.*—The surface soil of both Carrum and Dandenong Swamps is sandy, but contains a fair amount of organic matter and is, therefore, dark in colour. In Carrum Swamp, this surface layer is underlain by sand containing marine fossils, the most common of which is *Arca trapezia.* Behind Wells'-road, no shell layer could be found, although numerous channels were examined. This is in agreement with the supposition that, whereas the Carrum Swamp area has recently been covered by the sea, Dandenong Swamp has not.

Heavy minerals present in alluvium from Carrum Swamp and in silt and sand brought down by Dandenong Creek and deposited in the Main Drain include ilmenite, zircon, tourmaline and andalusite in all samples. Rutile and biotite were also present in some samples from Carrum Swamp. In the alluvium deposited in the Main Drain, the most noticeable feature is the abundance of biotite and hornblende (see table of heavy minerals, Nos. 4 and 5).

*Lunette Ridges.*—The depth of sand in these ridges is not very great, and in a section which has been cut through one of them, where it crosses Edithvale-road, the sand can be seen resting on a layer of clay and pebbles of limonite, which in turn rests on consolidated Tertiary grits at the same elevation as those exposed at the surface to the north of the ridge.

From what could be seen of the sand forming this ridge, it is unstratified as in typical lunettes. Mechanical analysis showed it to be less well sorted than normal dune sands as it contains several larger grains as well as some clay.

The heavy minerals present are the same as those found in the dune sands.

*Tertiary Sediments.*—Over the whole of the area from Brighton to Frankston, Tertiary rocks are exposed at the surface, or are present at no great depth beneath the sand and alluvial deposits.

West of the Cheltenham axis, these rocks outcrop along all the valley floors and are exposed beneath the sand in pits and sections through many of the ridges. They vary from pale-coloured clays found along the lower parts of Elsternwick Creek to ferruginous sandstones found towards Cheltenham and Mordialloc. Beneath the sand ridges, the Tertiary rocks are generally found at a higher

level than in the adjacent valleys, and consist mainly of loose and partly consolidated grits and sands, in some places very similar to the overlying dune sand except for the large percentage of clay present. These sediments can be seen in sections along the Frankston and Sandringham railway lines, and also in sand pits along Warrigal-road.

On the eastern side of the Cheltenham axis, the Tertiary rocks exposed differ from those described above chiefly in the absence of clays and the presence of unconsolidated grits and abundant limonite concretions.

In the Lyndhurst gravel pit, which is approximately 9 miles north-east of Frankston and 4 miles south-east of Dandenong, very fine unconsolidated sand, in which the grains are all $< \frac{1}{2}$ mm. in size (see Histogram No 23), is exposed at the bottom of the pit. It is not as well sorted as dune sand and contains a small amount of clay. Horizontal bedding can be seen where the sand has been partly cemented by limonite. Above this fine sand and apparently conformable with it are coarse sands mixed with larger quartz pebbles and clay, all of which are stained intensely red by limonite. Higher up, these sands pass into coarse grits and gravels.

The deposits are roughly stratified, and cross bedding is very common, but there appears to be no consistent direction of dip of the current-bedded layers. The most striking feature of most of these deposits is their intense red colour, due to limonite staining.

Very hard ferruginous grits outcrop approximately 3 miles east of Mordialloc between the main lunette ridge described above and the low sand dunes to the south of it (fig. 2). Over the rest of the Dandenong Swamp, no Tertiary rocks are found at the surface, but where bores or deep channels have been made, ferruginous grits and fine sands have been brought to the surface.

The grits again outcrop near the south-eastern boundary of Dandenong Swamp in the neighbourhood of Carrum Downs, and in this locality concretionary forms of limonite are common on the surface. Material brought up from a well situated about $\frac{1}{4}$ mile from the main Frankston-Dandenong road was found to consist almost entirely of fine white sand similar to that underlying the grits at Lyndhurst and Cranbourne, but without the limonite staining. Grits similar to those at Lyndhurst also outcrop at one point along Wells'-road, just north of Carrum Vale-road (fig. 2).

Results of mechanical analyses of sands and gravels from Lyndhurst and Cranbourne (Histograms Nos. 21-24) show that the coarser material has been very poorly sorted and this, combined with the irregular current bedding, suggests that these sediments have been deposited very rapidly, probably from rivers, and may perhaps be piedmont deposits.

Heavy minerals present in these grits include ilmenite, magnetite, zircon, tourmaline, rutile and andalusite. Rare grains of brookite were recorded in samples from Lyndhurst, and rare epidote from Cranbourne and also a pit on Warrigal-road. The various types of zircon—rounded, prismatic and stumpy—and also the different varieties of tourmaline, ranging from bluish-grey to pink and brown, are similar to the zircon and tourmaline grains present in the overlying sand deposits. Thus, all the heavy minerals found in the Tertiary deposits are also found in the sand ridges and beach deposits, with the addition of biotite in the beach deposits, and biotite and hornblende in the alluvium brought down by the Dandenong Creek.

In the Frankston area, Tertiary grits are exposed in many sections along the Frankston-Cranbourne road. These grits are similar to those found further north and west, but, in addition, they contain abundant large and well-formed flakes of kaolinite. Because of the size of these kaolinite " books," it is probable that the mineral has been formed after the deposition of the grits, in which it occurs, by alteration of felspars originally present.

Where the passage from Tertiary rocks to dune sand is exposed near one of the old Frankston sand pits near the Stony Point railway line, the dune sand can be seen resting on a layer of well-rounded and closely packed pebbles of Tertiary grits, approximately 1 inch in diameter. Below this is normal Tertiary rock. These pebbles may represent " lag gravels " left by the wind prior to the accumulation of sand forming the dunes. A similar layer of rounded pebbles was found overlying the Tertiaries near the corner of North-road and Boundary-road. Although this locality is just outside the area covered by the sand ridges, the gravels are overlain by approximately 3 feet of wind-blown sand drift. In all other sections where the passage from Tertiary rock to dune sand is exposed, no such gravels were found, and their local occurrence probably depends on the nature of the Tertiary sediments at that particular place.

## Summary of Lithology.

MECHANICAL COMPOSITION.

As can be seen from the histograms, dune and beach sands can be distinguished from other sediments by the small range in grain size and by the high degree of sorting. However, for differentiating between these two types of sands, a mechanical analysis does not prove very satisfactory if the sand alone is analysed and the presence or absence of pebbles ignored. Three small points of difference have been observed, and the most striking of these is the size of the chief ingredient, i.e., the predominating grain size. As has been pointed out above, in all the dune sands examined, the predominating grain size is between $\frac{1}{2}$ and $\frac{1}{4}$ mm., but in the beach sands it varies from place to place. In one sample, most of the grains are between 1 and $\frac{1}{2}$ mm. in diameter, whereas in another they are between $\frac{1}{4}$ and $\frac{1}{8}$ mm. Secondly, in the dune sand, the percentage of finer admixtures was found to be higher than that of the coarser admixtures, whereas in beach sands the reverse was found to be true. Thirdly, there is an almost complete absence of grains less than $\frac{1}{8}$ mm. in diameter from the beach sands.

As can be seen from the histograms, the range in grain size in the Upper Tertiary sediments is much greater than in the superficial sand deposits, and the degree of sorting is much less. Coarse grit, sands, and clay have apparently all been deposited simultaneously in the one spot, and this, together with the irregular current bedding, seems to exclude the possibility of their having been deposited under marine, esturine, or lacustrine conditions, and, as suggested above, they are probably fluviatile in origin.

*Roundness of Grains.*—In all the superficial sand deposits, the roundness of grains decreases with decreasing size. This is also true for the smaller grades in the Tertiary sediments, but in these, the larger grains ($>$ 2 mm. in diameter) instead of being more rounded, are more angular than the coarse sand fraction.

As far as could be judged by estimation alone, without any quantitative analysis of degree of rounding, there is no difference between the rounding of grains in beach sand and those in dune sands. In all the samples examined, there appears to be a mixture of very well rounded and angular grains. It does not seem probable that the large number of angular grains present, even in the coarsest grades of dune and beach sand, could be due to recent fracture of older grains, so that it may be suggested that the sand has been derived both from older sedimentary rocks and directly from igneous rocks. It would, therefore, be very difficult to determine the relative amounts of rounding due to wave action along the beach and to wind action during the formation of the

dunes, but, because of the short distance over which the dune sand has been transported by the wind, rounding due to this agency was probably very slight. It has been stated by Anderson (1926) that water is more effective in rounding grains than is wind, and that the beach presents the ideal situation for the rounding of sand grains.

*Stratification.*—As has been pointed out above, the fundamental difference in stratification of dune and beach sands is the uniform grain size of the former, and the variation from one lamina to the next in the latter. Current bedding is common in both types of deposit, and, although the angle of dip of the narrow laminae is variable, it is generally much less in the beach deposits than in the dune sands.

The regular horizontal bedding exposed in the Cheltenham, Warrigal-road and Clayton-road pits described above seems to be peculiar to the upper parts of the longitudinal dunes inasmuch as it has not been observed in any of the pits in the sandhills in the Frankston district.

*Heavy Minerals.*—The heavy minerals occurring abundantly in the dune sands, beach deposits and dune ridges, namely, ilmenite, zircon, tourmaline, and rutile, and, less commonly, magnetite, andalusite, and leucoxene, are similar to those found in the Tertiary sediments. Brookite, which is rare in all the sand deposits, is also present in the Tertiaries. Limonite, which is present in most of the samples from the recent sand formations, is absent from the Tertiary rocks as actual grains, although it is present as cementing material and in the form of concretions.

Of the minerals not found in all the sands, biotite appears to be the only one of any significance in relation to the origin of the deposits. It is common in sand on the beach, in the old beach deposits beneath the coastal ridge, in the alluvium from Carrum Swamp, and in material from the Main Drain in the Dandenong Swamp. On the other hand, it was not identified in any of the dune sands. This is in agreement with the findings of Retgers (1895), who suggested that, because of its form, biotite is seldom found in wind-blown sands. Its presence in the wind-blown sand forming the tops of the coastal ridges, however, is to be expected in view of the very short distance travelled by the sand from the beach, where biotite was abundant. Even so, the amount of biotite present in the blown sand is noticeably less than on the beach.

In conclusion, the abundance of well-rounded grains of ilmenite, tourmaline and rutile in all the sand deposits suggests that the sand has been derived largely from the pre-existing sedimentary rocks, since for these minerals to become rounded several cycles of erosion are usually necessary (Hatch, Rastall and Black, p. 92). As these minerals are similar to those occurring in the

Tertiary sediments, many of which are unconsolidated, it is probable that much of the sand now forming the inland dunes has been derived from these sediments. Any sand derived from igneous rocks as indicated by the angular condition of the grains, may have come by way of the beach from local granite outcrops near Frankston or from sand carried down from the Eastern Highlands by the rivers.

## Physiographic Evolution of Area.

All the sand dunes dealt with are now fixed by vegetation, and there is practically no movement of sand over the area excepting in the coastal ridges. The inland dunes must have been built up, therefore, at some time when there was no protective covering of vegetation, and any sand on the surface was free to be blown about by the wind. To account for these conditions, a much drier climate than that of the present day is necessary.

As has been pointed out above, longitudinal dunes having a north-westerly trend were formed in the Brighton area, and irregular barchan dunes in the Frankston area. As it seems to be generally accepted (Madigan, 1936; Hack, 1941; Bagnold, 1941) that longitudinal dunes are formed parallel to the prevailing wind, it is probable that the Brighton ridges owe their formation to either north-westerly or south-easterly winds. South-easterly winds would probably have brought rain, and it is therefore suggested that strong north-westerly winds blowing from the interior of the continent caused the formation of the longitudinal dunes over the sandy coastal plain.

The reason for the difference in form of the sand ridges in the north-west and south-east parts of the area is probably due to differences in the original topography, and in the sand supply. The origin of various types of dunes has been investigated by Hack (1941), who suggested that longitudinal dunes are developed only over flat areas with a meagre sand supply, whereas barchans require a much greater sand supply for their formation.

A brief investigation of the Tertiary rocks underlying the sand deposits revealed that in the extreme north-west of the area clays and consolidated grits outcrop at the surface; over the Brighton area unconsolidated sands and grits were found only beneath the ridges, and are probably of no great depth. In the central sector, the thickness of the loose sands and grits, judging from the available exposures, is much greater than further north-west. Assuming that the dunes were formed by prevailing north-west winds,

the amount of sand available for their information, therefore, was probably much greater towards the south-eastern part of the area than in the extreme north-west.

The coastal plain of the Brighton district is still relatively flat, except for the ridges and, given the required conditions of wind and sand supply, longitudinal dunes would be formed over this area. In the Frankston district, hills of Silurian rock and outcrops of Tertiary grits now project above many of the sand ridges, indicating that the topography of this part of the area was much more irregular than further north-west, and thus longitudinal dune ridges would not be formed in this district.

The drainage system, which developed in the north-western part of the area after the period of dune formation had been brought to a close by a return to moisture conditions, has been determined by the position of the sand ridges rather than by the general slope of the country, which is towards the south-west, and the streams now occupy the valleys which were formed simultaneously with the sand ridges, and therefore trend north-west. The direction of drainage is reversed along the Cheltenham axis, however, and the streams flow south-east towards Carrum Swamp. The presence of this minor divide is due to structures in the underlying Tertiary rocks. Although they are almost horizontal or dip at very slight angles over most of the area, at Beaumaris Bay the beds dip S.E. at 25° and flatten out again on either side, thus forming a monoclinal fold. The low divide, which has been described by Hart (1913) as the "Notting Hill-Cheltenham axis," follows the strike of this fold from Cheltenham to Mitcham. Since there is no abrupt change in the form of the sand ridges crossing the divide, it is probable that inequalities in level of the surface produced by the folding were almost smoothed out by erosion before the formation of the sand ridges.

Another tectonic feature in the underlying rocks which has helped to determine the present physiography is Selwyn's Fault in the south-eastern part of the area. Relative subsidence of the land between the monoclinal fold and Selwyn's Fault has been the chief factor in determining the position of Carrum and Dandenong Swamps, which, however, are of a much later date than the tectonic movements.

The presence of isolated sand hills projecting slightly above the level of the alluvium of the Dandenong Swamp (fig. 2) indicates that this flat area was also covered by sand dunes at one time, but

these have probably been eroded to a much greater extent than those to the north-west and south-east, because of the concentration of drainage into this relatively low-lying area. This area probably did not become a swamp until after a general rise of sea level caused the flooding of Port Phillip Bay and brought the coastline approximately to the position of the Wells'-road ridge. It is probable that the coastline was at first rather more irregular and for a very short time was a little further inland than this ridge, which may have been formed first as an off-shore bar and later became the coast as the depression behind it was silted up. As the dune ridge was built up along the former shoreline, drainage from the Dandenong and Eumemmering Creeks was impeded, and the water spread out, forming swamps in which most of the sand from the ridges was removed and redistributed, and the remaining sand hills partially or completely buried. The lunette ridges, situated as they now are along the northern boundary of the alluvial flats, were built up on the northern sides of the swamps, suggesting that the dominant wind causing sand movement was at this time from the south or south-west and not from the north-west as during the dry climatic period.

Recession of the coastline from Wells'-road to its present position, with the consequent formation of a younger dune ridge separating Carrum Swamp from the sea, resulted from a recent emergence of the coastline (Hills, 1940B).

The presence of the depression occupied by Kananook Creek indicates that there are at least two dune ridges very close together. This fact, together with the presence of beach deposits and shell beds $3\frac{1}{2}$ feet above high-tide mark, suggests that there has been a more recent emergence of at least $3\frac{1}{2}$ feet, probably a little more. This is in agreement with further evidence given by Hills (1940B) for a recent emergence of the shores of Port Phillip Bay.

## Acknowledgments.

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[PROC. ROY. SOC. VICTORIA, 56 (N.S.), PT. I., 1944.]

# ART. V.—*The Geology of the Port Campbell District.*

By GEORGE BAKER, M.Sc.

[Read 8th July, 1943; issued separately 1st August, 1944.]

## Abstract.

In the coastal cliffs east and west of Port Campbell township, Middle Tertiary calcareous clays and limestones are assigned a (?) Balcombian age, while underlying deposits between Glenample Steps and a locality ¾-mile N.W. of the Gellibrand River are classed with the Balcombian from palaeontological and lithological correlation with beds of that age described from other parts of Victoria. Balcombian and (?) Balcombian sediments outcrop for over 15 miles along the coast, are from 750′-1,000′ thick, and conformably overlie a thin series (60′-100′) of deposits composed of grit, conglomerate, limestone and calcareous clay, probably of Janjukian age. Unfossiliferous beds beneath and conformable with the Janjukian sediments may be Oligocene. The sediments are principally horizontal with occasional gentle undulations and a few small faults. They dip down to form a broad, shallow syncline in the west of the area, and have low westerly dips in the south-east. The Balcombian, Janjukian and (?) Oligocene deposits are apparently conformable with westerly dipping Eocene rocks which occur south-east of the Gellibrand River and unconformably overstep Jurassic rocks. The general indications in the Tertiary beds are that an uninterrupted sequence of deposition occurred from Eocene to Balcombian times, after which this theatre of sedimentation was elevated to form a land mass. Post-Miocene clays form a thin veneer on the Middle Tertiary rocks. Pleistocene dune limestone has infilled the valley of the pre-Pleistocene ancestor of the Gellibrand River. Recent deposits occur along present river courses, at the base of the coastal cliffs in parts of the area and across the mouths of the larger watercourses.

## Introduction.

The Port Campbell district is situated on the south-west coast of Victoria. The area investigated constitutes the coastal strip of the southern portion of the county of Heytesbury, and stretches from Peterborough in the west to a point two and a half miles south-east of Princetown (fig. 1).

The oldest Tertiary rocks of the area are exposed in the sea-cliffs at Pebble Point in the south-east. They are grits and sandy ironstones of Eocene age, overlain by fossiliferous clays and sandstones which are also probably Eocene (1, 30, 33). Unfossiliferous ferruginous and carbonaceous sandstones above the Eocene beds may be of Oligocene age. This series of deposits occurs S.E. of the Gellibrand River.

Fossiliferous limestones, argillaceous limestones and calcareous clays of Miocene age outcrop extensively to the west and north-west of the Gellibrand River. They are soft rocks which form

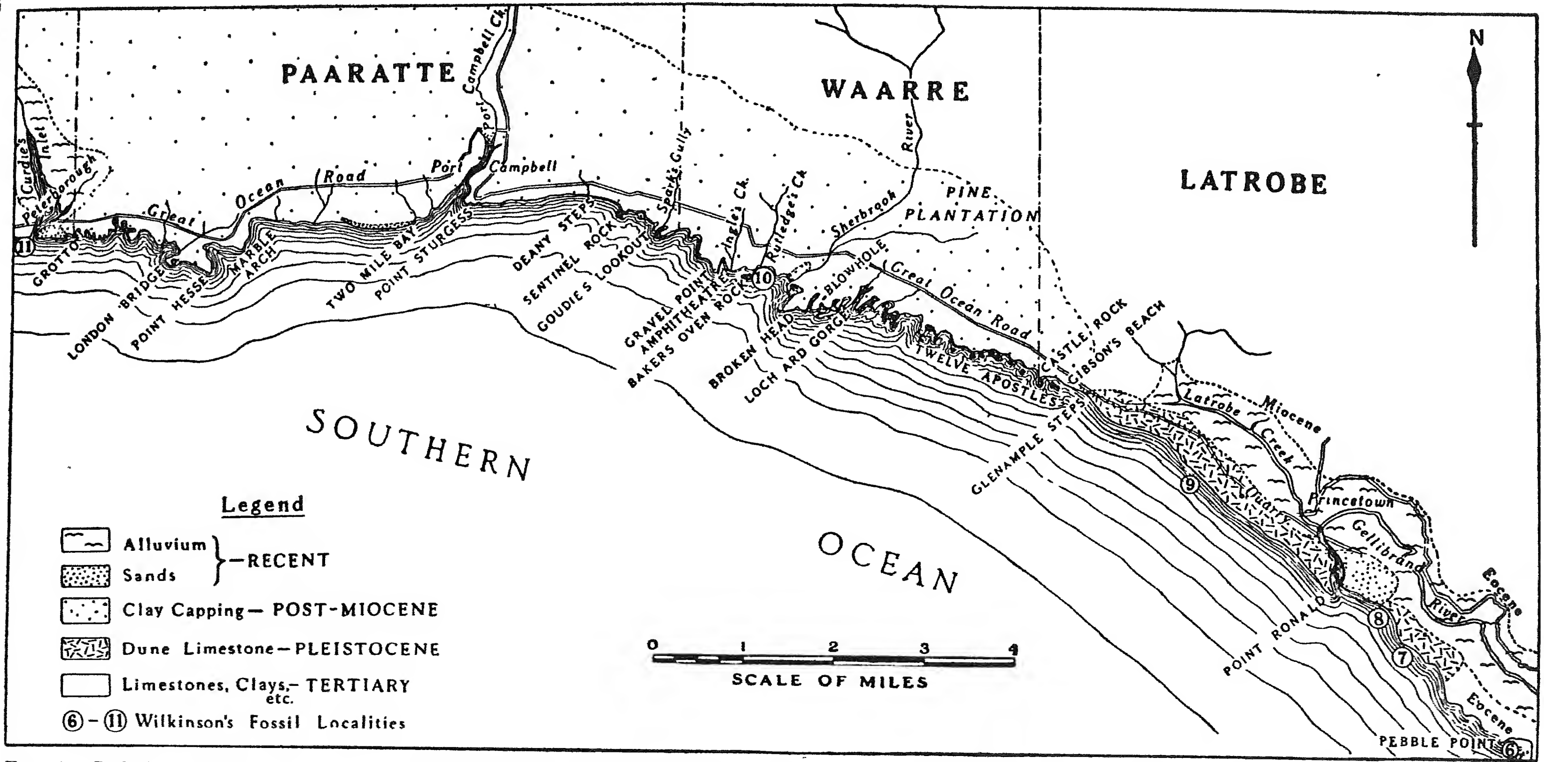


FIG. 1.—Geological Sketch Map of the Peterborough–Port Campbell–Princetown Coastal Area, showing place names. Outline compiled from State Parish Plans in the County of Heytesbury.

the high, vertical cliffs so characteristic of the coastline from Glenample Steps (fig. 1) to Peterborough.

The basal members of the Tertiary deposits, i.e., the Eocene beds, rest unconformably, with some overstepping, upon an erosion surface in Jurassic arkoses and mudstones which form widespread outcrops in the Cape Otway Peninsula.

The Miocene beds are classified principally with the Balcombian series from the results of detailed investigations of the foraminiferal content of various members of the deposits by Mr. W. J. Parr (see appendix), and from the preliminary examination of the molluscan fauna by Dr. F. A. Singleton.

A veneer of clays on the Tertiary deposits is regarded as of post-Miocene age. The vertical nature of the cliffs in the district renders many parts of the Tertiary exposures inaccessible. Nevertheless, such portions of the cliffs as could be studied provide considerable evidence of the age sequences in the Tertiary succession. The Tertiary rocks of the coastal sections in the immediate vicinity of Princetown are partially obscured by considerable thicknesses of Pleistocene dune limestone for a distance of approximately 4 miles. This portion of the area represents an infilled valley of the ancestor of the Gellibrand River. Recent, partially fixed calcareous sand dunes have been built up on the consolidated Pleistocene dune limestone in this part of the area, and also on eroded Tertiary rocks at the mouths of the Curdie and Sherbrook Rivers. Behind river-mouth sand dunes and beach sand-ridges along the coast, deposits of sand and alluvium have accumulated, more particularly upon the valley floors of Port Campbell Creek, the Sherbrook and Gellibrand Rivers and Curdie's Inlet. The Recent deposits of the Gellibrand River and of Curdie's Inlet contain shallow-water marine, as well as fluviatile, sediments.

## Previous Work.

The area was originally surveyed by C. S. Wilkinson in 1865, when all of the Tertiary rocks in the district were regarded as Lower Miocene in age (34). The accompanying section (fig. 2) was prepared by Mr. A. E. Kennedy, of the Victorian Mines Department, from the original by Wilkinson. It has not been published previously, and portrays, with a considerable degree of accuracy, the general relationships of the Mesozoic, Tertiary and post-Tertiary rocks from Moonlight Head in the south-east, to Warrnambool in the west. This section embraces the Peterborough-Port Campbell-Princetown coastal sections, recent investigations of which show a few minor departures from Wilkinson's original work. The numbers on the section refer to Wilkinson's fossil localities. The vertical scale, not noted by Wilkinson, is approximately $\frac{1}{8}'' = 250$ feet.

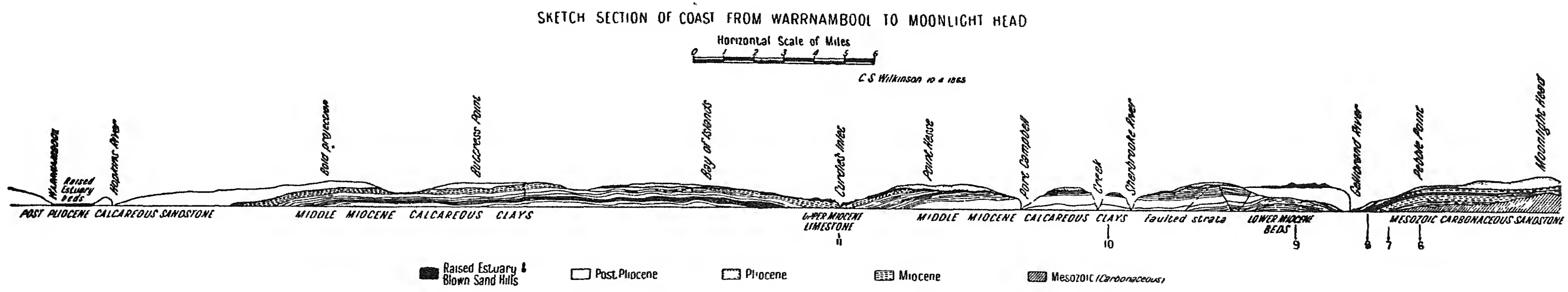


FIG. 2.—Wilkinson's Section from Moonlight Head to Warrnambool

In 1868, H. M. Jenkins examined fossils collected from the area, and classified the beds immediately N.W. of the mouth of the Gellibrand River as Miocene, stating that the most important bed was a dark, slate-coloured, stiff clay, very rich in fossils and remarkable for yielding perhaps the finest examples of Cypraea which occur in the fossil condition. Jenkins regarded deposits near the Sherbrook River (at a locality now known as the Rutledge's Creek coastal section), from which he recorded *Trigonia lamarcki*, as probably being referable to the same horizon as the Mordialloc deposits in Port Phillip Bay, characterized by the same form of Trigonia, and mapped as Lower Pliocene by the Victorian geological surveyors (19). It is now known, however, that this Trigonia at both these localities is not *Neotrigonia lamarcki*, a recent species from the New South Wales coast, but is *Neotrigonia acuticostata* (McCoy), a closely allied species described from Beaumaris.

In 1870, P. M. Duncan reproduced the results of elaborate surveys made by Victorian geologists, and described the corals collected from the deposits between the Gellibrand River and Moonlight Head (13). Later, he described the echinoids from various portions of the area (14).

In 1877, R. A. F. Murray included additional notes on this area in his report on the Cape Otway district (23), giving details concerning the marshy flats of the Gellibrand River, the dune rock at the mouth of this river, the age relations of some of the Tertiary deposits, and correlations with Tertiary outcrops in other parts of Victoria.

Various ages have been assigned to the Tertiary deposits of the Port Campbell and neighbouring coastal sections from time to time. Tate (31), Tate and Dennant (32), Pritchard (25, 26, 27 and 28), Maplestone (20, 21 and 22), Dennant and Kitson (12), Chapman (2-8), Hall (15, 16), Chapple (9, 10) and Parr and Collins (24) have described various fossils from the several component beds of the Tertiary deposits between Peterborough and Pebble Point. Most of these authors correlated individual fossils or suites of various groups of the invertebrate fossils with those found in other Victorian Tertiary deposits. The results of the correlations have varied as a consequence of changes in opinion concerning the general sequence of the Tertiary succession in Victoria. Recent ideas concerning this succession are set out by Singleton (29, pp. 63-64), and included in his table of correlation are some of the Tertiary deposits of the Port Campbell district.

The various opinions relating to the age of the Port Campbell Tertiary rocks are summarized in Table 1, where localities elsewhere in Victoria, with which certain of the Port Campbell strata have been correlated, are also tabulated.

TABLE 1.

| Location of Beds. | Age | Author. | Date. | Correlated Localities. |
|---|---|---|---|---|
| Deposits between Gellibrand River and Moonlight Head (= Pebble Point Beds) | Miocene .. | Duncan .. | 1870 | Beds at Aire River Castle Cove. Locality 1 mile east of Point Addis |
| ,, ,, ,, | Middle Tertiary (Miocene) | Murray .. | 1877 | |
| ,, ,, ,, | Upper Eocene | Dennant and Kitson | 1903 | |
| ,, ,, ,, | Barwonian (Balcombian) | Chapman .. | 1904 | |
| ,, ,, ,, | Lower Janjukian | Pritchard .. | 1923 | |
| ,, ,, ,, | Eocene .. | Teichert, Singleton, Baker | 1943 | |
| Gellibrand Clays, 3 miles north-west of mouth of Gellibrand River | Lower Miocene | Wilkinson .. | 1865 | Orphan Asylum Reserve, Fyansford, near Geelong |
| ,, ,, ,, | Miocene .. | Jenkins .. | 1868 | |
| ,, ,, ,, | Lower Oligocene | McCoy .. | 1874–1882 | |
| ,, ,, ,, | Eocene .. | Tate and Dennant | 1893–1896 | |
| ,, ,, ,, | Lower Tertiary (Oligocene) | Murray .. | 1877 | Point 2 miles west of Cape Otway. East bank of Aire River. Coast between Aire River and Castle Cove. Coast between Mt. Eliza and Mt. Martha |
| Gellibrand Clays, 3 miles west of mouth of Gellibrand River | Upper Eocene | Tate .. | 1899 | |
| ,, ,, ,, | Eocene .. | Pritchard .. | 1901 | |
| ,, ,, ,, | Balcombian (Eocene) | Pritchard .. | 1904 | |
| ,, ,, ,, | Barwonian (Eocene) | Tate and Dennant | 1904 | Muddy Creek (lower beds). Mornington. |
| ,, ,, ,, | Janjukian (Miocene) | Chapman and Gabriel | 1923 | |
| ,, ,, ,, | Janjukian (Miocene) | Chapman and Singleton | 1925 | |
| ,, ,, ,, | Lower Miocene | Chapman and Crespin | 1935 | Basal beds at Sherbrook River. Lake Gnotuk and Lake Bullenmerri near Camperdown |
| ,, ,, ,, | Balcombian (Middle Miocene) | Singleton .. | 1940 | Muddy Creek (lower beds). Mornington. Fyansford. Barwon River. Mitchell River. Lower part of Sorrento bore. Upper beds at Maude. Ironstones at Keilor and Royal Park (lower beds) |
| Loch Ard Gorge (Lower portion) | Middle Miocene | Chapman and Crespin | 1935 | Peterborough |
| Loch Ard Gorge (Upper portion) | Upper Miocene | Chapman and Crespin | 1935 | Lake Gilleah near Allansford. First and second creeks (Rutledge's and Ingle's) west of Sherbrook River |
| Sherbrook River .. | Eocene .. | Tate and Dennant | 1893–1896 | |
| ,, ,, | Barwonian (Eocene) | Hall .. | 1907 | |
| ,, ,, | Barwonian .. | Chapman .. | 1914 | European Miocene |
| Sherbrook River (Basal beds) | Lower Miocene | Chapman and Crespin | 1935 | Gellibrand River, near Princetown |

TABLE 1.—*continued.*

| Location of Beds. | Age. | Author. | Date. | Correlated Localities. |
|---|---|---|---|---|
| Creek 1 mile west of Sherbrook River (= Rutledge's Creek) | Lower Pliocene | Jenkins .. | 1868 | Mordialloc beds |
| ,, ,, ,, | Middle Miocene | McCoy .. | 1874–1882 | |
| ,, ,, ,, | Middle Miocene | Murray .. | 1877 | |
| ,, ,, ,, | Janjukian (Miocene) | Chapman and Gabriel | 1923 | |
| ,, ,, ,, | Janjukian (Miocene) | Chapman and Singleton | 1925 | |
| ,, ,, ,, | Upper Miocene | Chapman and Crespin | 1935 | Lake Gilleah near Allansford |
| Rutledge's Creek (Upper beds) | Kalimnan (Lower Pliocene) | Chapman and Crespin | 1935 | Forsyth's (Grange Burn) McDonald's (Muddy Creek). Russell's Creek (Warrnambool). Portland (lower beds). |
| Rutledge's Creek (Lower beds) | Cheltenhamian (Upper Miocene) | Singleton .. | 1940 | Upper beds at Beaumaris. (?) Middle part of Sorrento bore |
| Port Campbell .. | Eocene .. | Tate and Dennant | 1893–1896 | |
| Two Mile Bay .. | Barwonian (Eocene) | Hall and Pritchard | 1905 | Curlewis (Oligocene of McCoy; Miocene of Chapman) |
| Curdie's Inlet .. | Miocene .. | Parr and Collins | 1937 | |
| Calcareous Sandrock, Gellibrand River | Post-Pliocene | Jenkins .. | 1868 | |
| ,, ,, | Recent (Upper Pliocene) | Murray .. | 1877 | |
| Clays above Tertiary Rocks along coast, Port Campbell | Upper Tertiary | Murray .. | 1877 | |

It can be seen from Table 1 that the clays of the Gellibrand River section have been classed by different authors into various stages of the Tertiary System—Eocene (26 and 32), Upper Eocene (31), Lower Oligocene (23), Oligocene (23), Lower Miocene (6), Middle Miocene (29) and Miocene (13, 34), while the beds stratigraphically higher than these clays (i.e., at Loch Ard Gorge, Sherbrook River and environs, &c.) have been variously placed in the Eocene (16), Lower Miocene (6), Middle Miocene (29), Upper Miocene (29) and Lower Pliocene (6). The correlation of the Gellibrand Clays (= Princetown Clays) with the Mornington and Muddy Creek (Lower) beds by Tate and Dennant (32) and by Murray (23), i.e., with beds regarded as belonging to the Balcombian marine stage of Tertiary sedimentation, is supported by the remarkable faunal and lithological similarities, although Murray (23) also correlated the Gellibrand Clays with beds at the Aire River and elsewhere along the Cape Otway coast, at localities where the beds are regarded as of (?)Janjukian age (Upper Oligocene to Lower Miocene) by Singleton (29). The beds near the mouth of the Sherbrook River (i.e., the coastal section at Rutledge's Creek) were correlated by Jenkins (19) with the Mordialloc (i.e., Beaumaris)

beds as Lower Pliocene. The upper layers of the deposits at Beaumaris have recently been classed as of Cheltenhamian (Upper Miocene) age (29).

The age assigned to the greater proportion of the Tertiary deposits N.W. of the Gellibrand River, from the present investigations, is Balcombian (Middle Miocene) and (?)Balcombian. The area, therefore, provides us with perhaps the finest and most extensive sections of Balcombian rocks yet recorded from Victoria. The following notes supply additional information concerning the nature of the Tertiary deposits and their fossil content. The mineralogical and petrological characters of the various rock types represented in the Port Campbell district have also been investigated.

## STRUCTURAL FEATURES.

The Tertiary deposits of the coastal strip appear in the cliff sections between Peterborough in the west, and Glenample Steps in the east, mainly as a horizontal series of strata (Pl. II., figs. 1 and 3). Their horizontal disposition is accentuated by the formation of prominent, level, wave-cut platforms, wave-cut notches and storm benches, which have been developed along the bedding planes separating strata of slightly different solubility and hardness. The coast trends in a north-westerly direction in the eastern portion of the area, and east-west in the western portion. There is a general gentle seaward inclination (Pl. II., fig. 2) in the beds of up to 5°, as can be observed in transverse sections. At the Baker's Oven Rock and on the west side of the harbor at Port Campbell, dips of from 2° to 4° are present, while lower dips of about 1° occur at Loch Ard Gorge, London Bridge, in a bayside cliff west of the Amphitheatre, &c. The early geological survey officers, Wilkinson (34) and Murray (23), recorded the dip of the beds near the Gellibrand River (Pl. II., fig. 4) as 5° to the north-west, but Tate and Dennant recorded the dips as 4° in a west 12° south direction (32, p. 213). These are the maximum dips for the Tertiary beds west of the mouth of the Gellibrand River and east of Peterborough. Lower dip values result from the variable directions in which local coastal indentations cut across the direction of true dip. South-east of the mouth of the Gellibrand River, at small headlands in the vicinity of Pebble Point, the Eocene deposits dip at angles of 5° in much the same direction as the younger Tertiary sediments west of the river mouth (1). Low dips thus occur in the coastal sections both between Point Ronald (at the mouth of the Gellibrand River) and Pebble Point and between Point Ronald and Glenample Steps, but east and west of these localities the beds are more or less horizontal. Wilkinson recorded easterly dips in the Tertiary beds 40 chains west of the mouth of the Gellibrand River, and he considered that the Miocene strata 3

miles north-west of the river mouth occurred at the apex of an anticlinal curve (34, and see fig. 2). The author is unable to agree with these observations, having found that clays and sands 40 chains west of the Gellibrand River dip westerly 5° (Pl. III., fig. 12). No anticlinal structure was found 3 miles north-west of the Gellibrand River. The broad, shallow syncline at Peterborough, shown by Wilkinson in fig. 2, is proved by the disappearance of the Tertiary clays below sea level for about a mile on each side of Curdie's Inlet. Elsewhere in the coastal cliffs east and west of Peterborough, the clays form the lower 40′-60′ of the cliffs. The Curdie River apparently followed this synclinal structure.

The direction of elongation of certain of the rock stacks, gorges and heads of bays, and the trend of prominent cracks on wave-cut benches, indicate that some of the joint planes in the Tertiary rocks are parallel with the general trend of the coastline (i.e., N.W.-S.E. in the western part of the area). Others trend N.E.-S.W., parallel with other gorges and promontories in the central to eastern portion of the area. Some of the joint planes are vertical, and so control the nature of the cliff faces, others dip into the cliff faces at lower angles (e g., west wall of Loch Ard Gorge, where the joints dip at 45°) and control the slope of the roofs of caves. Jointing in the Tertiary clays south-east of Glenample Steps is closely spaced, and appears to have resulted from recent alternate wetting and dessication of steeply inclined cliff faces (Pl. III., fig. 10).

Intraformational contortion in a band of highly plastic clay about 6 feet wide occurs among the dipping Tertiary series south-east of Glenample Steps (Pl. III., fig. 8). It can be traced for a few chains in the cliffs, and probably resulted from the movement of hydrated clays under the influence of the pressure of the overlying beds (18, Pl. 1), or from subaqueous slumping (18, p. 15).

Many of the bedding planes in the Tertiary rocks, especially those in the upper portions of the cliffs are marked by concentrations of nodules and sheets of secondary calcium carbonate (Pl. II., figs. 3 and 4), the nodules assuming rounded, cylindrical and irregular shapes.

The Tertiary beds throughout the area form an apparently conformable series, although, at Curdie's Inlet, Wilkinson stated that the soft, yellow limestone containing a few fossils, appeared to rest unconformably upon the underlying calcareous clays, since the limestone filled up small hollows in the upper beds of the calcareous clays (34). The Tertiary beds in the south-eastern portion of the area are unconformable to the Jurassic beds, while the base of the overlying non-stratified post-Miocene clays in the

western and central portions of the area is sharply delimited from the Tertiary deposits. The Pleistocene dune limestone rests unconformably upon Eocene, (?)Oligocene and Miocene sediments.

Wilkinson recorded numerous small faults in the cliff sections at Port Campbell; five or six were said to occur in a short distance (1 mile) (34). A few faults observed by the author are thrust faults; a small one in a cliff section north-west of Castle Rock has a stratigraphical throw of about 2 feet, and a hade of 25° in an east of south direction. Others of like nature occur in the cliffs west of Sherbrook River and in Thunder Cave at the head of Survey Gorge, half a mile west of Loch Ard Gorge. Minor variations in height of the more clearly-marked junctions between certain beds in less accessible portions of the cliff faces may be due to small faults, but may have resulted from local warping of the gently dipping strata.

In the western portion of the area, local sagging of the limestone beds in the vicinity of the Grotto has resulted in small-scale collapse structures (Pl. II., fig. 6). The motive force responsible for their development is gravity (17). The limestone has been bent and broken by slipping over calcareous clay deposits into caves dissolved in the underlying beds. Similar small-scale, monoclinal flexures are less clearly marked in the cliffs of the immediate neighbourhood.

Chemical banding by the rhythmic precipitation of colloidal iron oxide occurs in patches in the Tertiary limestones and calcareous clays as at the Amphitheatre, at the Rutledge's Creek coastal section, and in the cliffs near Hennessy Steps (east of Broken Head).

In the Jurassic sediments outcropping in the south-eastern portion of the area, current bedding and honeycomb and cannonball structures have been brought into prominence by differential weathering.

## Stratigraphical and Palaeontological Relationships.

### Eocene.

The nature and relationship of the westerly dipping Eocene beds, with a strong littoral fauna, S.E. of the Gellibrand River mouth, have already been described (1, 30, 33). Since that description, W. J. Parr has found an outcrop of fossiliferous, glauconitic clay at a locality about 1 mile N.W. of Pebble Point, near the two recorded bands of sandstone, one containing *Turritella* sp. and the other *Trochocyathus* with *Odontaspis*. Foraminifera, corals, pelecypods, gasteropods, scaphopods and shark's teeth occur in the glauconitic clay. Mr. Parr has examined

the foraminifera and concluded that the assemblage is similar to that in the Pebble Point Beds (Eocene). This evidence lends further proof to the conclusion drawn from the lithological character and disposition of the sediments immediately above the Pebble Point Beds (1), that they are also of Eocene age. The Eocene deposits south-east of the Gellibrand River, therefore, include the Pebble Point Beds and the overlying fossiliferous clays with intercalated sandstone beds, up to the base of the non-fossiliferous sandy clays and ferruginous sandstones which occur half a mile south-east of Point Ronald.

## (?) Oligocene.

Unfossiliferous beds immediately above the Eocene, which have the same dip in the same direction as the Eocene deposits, may be of Oligocene age, but there is as yet no conclusive evidence to establish this. A bed of carbonaceous sandstone in this series bears certain lithological resemblances to carbonaceous sandstone at Anglesea in Victoria, but does not contain *Odontaspis contortidens* (Ag) or *Cyclammina,* which have been recorded from the Anglesean series, classed as Oligocene (29). The lowest (unfossiliferous) beds of the westerly dipping Tertiary deposits on the other side (i.e., north-west) of the Gellibrand River have no counterparts among those of unproven age which rest conformably upon the Eocene. This, and the fact that the direction and amount of dip are similar for outcrops on each side of the river mouth, lead to the assumption that the oldest beds exposed N.W. of the Gellibrand are younger than the youngest beds exposed S.E. of the river. This again, however, is not conclusive, because nothing is known of the beds or structures that existed in the gap created in the Tertiary rocks by the pre-Pleistocene ancestor of the Gellibrand River. If a continuous series of westerly-dipping beds is hidden beneath the Quaternary deposits at this locality, it should, according to calculations, be some 350-400 feet thick.

## Miocene.

Extending for a distance of 2 to 2½ miles west of the mouth of the Gellibrand River, various exposures of the Tertiary beds form the lower 30 to 40 feet of the cliffs, but in many places between Point Ronald and Glenample Steps are obscured by large talus deposits (Pl. III., fig. 9) derived mainly from Pleistocene dune limestone. The Pleistocene forms the upper parts of the cliffs from a few yards east of Glenample Steps to within 30 chains of Point Ronald (at the mouth of the Gellibrand River), after which it comes down to sea level and forms the entire cliffs at Point Ronald (fig. 3), and the wave-cut platform and reefs half-a-mile south-east of the mouth of the Gellibrand River.

Thirty chains west of the Gellibrand River mouth, Wilkinson (34) recorded east-dipping Tertiary rocks, and at a section 10 chains further west he found 7 feet of unfossiliferous, blue, sandy clay with a few quartz pebbles, overlain by 20 feet of yellow, red and grey sandy clay with no fossils. The author found that these are really west-dipping Tertiary beds at this locality (Pl. III., fig. 12). Half-a-mile north-west of Point Ronald, outcrops of Tertiary beds, occasionally visible among piles of large fallen blocks of dune limestone, consist of ferruginous gritty sandstone, about 15 feet thick at the base (lower limit hidden by Recent beach sands), with occasional bands of dense ironstone but no fossils visible in hand specimens. This is overlain by a lenticular bed 1-8 feet thick (Pl. III., fig. 11), containing abundant ferruginous pebbles 3-4 inches across, and ferruginous internal casts and external moulds of gasteropods like *Cypraea* sp., &c. On breaking, some of the pebbles are seen to contain casts of pelecypods. Sharks' teeth are also present in the matrix of the deposit. Wilkinson regarded the pebbles as rolled fragments of fossiliferous Miocene clays (34). Some of the matrix in which the pebbles are set consists of ferruginous gritty sandstone comparable to the underlying bed, and some of the pebbles are phosphatic. The fossil casts and moulds appear to belong to the deposit (i.e., not remanié), and are merely replaced by ironstone. Gritty limestone containing a band of ironstone 1 foot thick overlies the conglomerate, and forms part of the matrix in which the ferruginous, phosphatic nodules are set. A Janjukian shelly fauna occurs in this bed and in the overlying limestone. Forms such as *Graphularia senescens* (Tate), *Mopsea* cf. *coralloides* Ed. & H., *Flabellum distinctum* Ed. & H., various additional types of corals, *Paradoxechinus novus* Laube, *Lovenia forbesi* (T. Woods), echinoid spines, *Cellepora gambierensis* T. Woods, *Schizellozoon* sp., *Spondylus gaderopoides* McCoy, *Chlamys, Pallium (Mesopeplum)* aff. *palmipes* (Tate), *Willungia tasmanica* Powell, *Umbilia* cf. *platyrhyncha* (McCoy), *Conus* sp., and sharks' teeth, are present in this matrix. Additional features are large Nodosarians, well preserved Cidaroid spines, and round, brown-coloured grains of quartz about the size of a pea. The overlying gritty limestone is 15 to 20 feet thick, and contains abundant polyzoa and various echinoids, in addition to those fossils observed in the matrix of the ferruginous, phosphatic conglomerate. A few feet of fossiliferous clays, probably of Janjukian age, exposed above the gritty limestone, are overlain by Recent sands and talus. These clays contain a few species of foraminifera found in Janjukian beds in other parts of Victoria, but the greater part of the foraminiferal assemblage is composed of Balcombian species.

The outcrop of this series of beds can be traced along the beach section for about 40 yards. All of its members are conformable and dip 2½° westerly. At the north-west end of the exposure of ferruginous conglomerate and grits, fossiliferous blue and grey coloured clays appear. They are conformable with the beds containing macrofossils with a Janjukian aspect, and are westerly continuations of the clays resting upon the gritty limestone. The gritty limestone bed having a macro-fauna with Janjukian affinities may, with the clay immediately above it and the underlying non-fossiliferous beds, represent Upper Oligocene deposits, as Singleton (29) regards Janjukian beds as of Upper Oligocene to Lower Miocene age. There is no marked Batesfordian phase between the gritty limestone of Janjukian age, and the overlying conformable clays which grade into true Balcombian.

Further north-west of this locality, extending to about 2½ miles from Point Ronald, grey Tertiary clays form fairly steep cliffs 30 to 40 feet high (Pl. III., fig. 9). The clays in the cliff sections here are of Balcombian age, and extend north-west to the dipping Balcombian clays so prominently exposed in the high cliffs nearer Glenample Steps (Gibson's Beach). They contain abundant Balcombian fossils including, among others, foraminifera (see appendix), corals, polyzoa, rare brachiopods and rare echinoids, numerous molluscs among which are *Limopsis morningtonensis* Pritchard, *L. maccoyi* Chapman, *Glycymeris gunyoungensis* Chapman & Singleton, *Pterospira hannafordi* (McCoy), *Ellatrivia minima minima* (T. Woods), *Zoila platypyga* (McCoy), *Gigantocypraea gigas* (McCoy), *Dentalium mantelli* Zittel and *D. subfissura* (Tate), and *Aturia australis* (McCoy). Abundant small gasteropods are also present.

The clays and argillaceous limestones in the cliff sections south-east of Glenample Steps (i.e., at the locality referred to in earlier works as "three miles west of the Gellibrand River mouth"), correspond with Wilkinson's No. 9 locality (34). They dip south of west at 5° at the eastern end of the exposures. but the angle of dip decreases to 2° at the first headland east of Glenample Steps. The beds become horizontal near Glenample Steps and remain more or less so for over 20 miles in a westerly direction along the coastline, after which they dip westerly at low angles.

The fossil species from the beds in the cliff sections three miles north-west of the mouth of the Gellibrand River, many (260) of which are listed by Tate and Dennant (32, p. 218-226) and by Dennant and Kitson (12), and the lithological characters of the beds are comparable to those of the Muddy Creek (Lower) and Balcombe Bay beds, which are regarded as of Middle Miocene

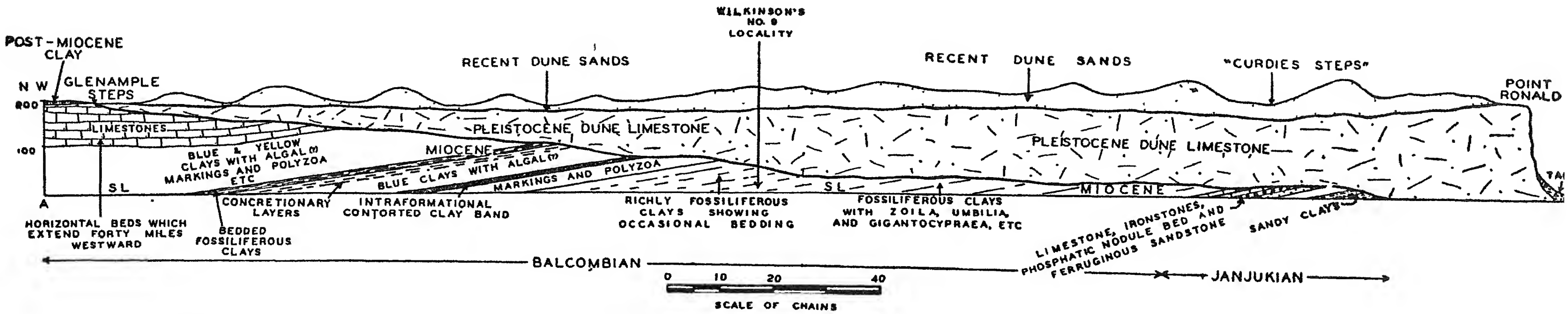


FIG. 3.—Geological Sketch Section, illustrating diagrammatically the coastal sections from Glenample Steps in the north-west to Point Ronald in the south-east. Le[illegible] of section is just over 3½ miles. Heights above sea-level are up to 250 feet. The dip of the Tertiary beds is exaggerated.

age (29, p. 63-64). In parts, the clays are shale-like in appearance on account of the frequent parallel lineation of markings resembling algal remains. At this locality, a calcareous clay band containing *Umbilia eximia maccoyi* Schilder, *Umbilia leptorhyncha* (McCoy), *Zoila platypyga* (McCoy) and other gasteropods, occurs some 30 feet stratigraphically higher than another depositional phase of the clay containing *Cerithium apheles* T. Woods and *Gigantocypraea gigas* (McCoy). Between these two bands, and in the base of the cliffs further north-west of this locality, extending to Glenample Steps, the Lower Tertiary clays are chiefly blue-grey in colour. They contain numerous sinuous and concentric markings tentatively referred to as algal remains (Pl. III., fig. 7), a few species of foraminifera, *Ditrupa,* and sporadic patches with branching forms of polyzoa and molluscs. The curious branching and pipe-like markings which sometimes appear concentric in cross-sectional aspect, are alternating darker and lighter bluish-grey-coloured, laminated clay. They are often flattened, and although referred to as (?) algal markings, they do not show any definite plant-like structures. Dr. M. F. Glaessner has suggested to me the possibility of the markings being due to burrowing animals such as marine worms and the like. The remains of mud-haunting crabs and spatangoids in various parts of the Tertiary rocks suggest that the markings may be a result of their burrowing activities. Clays with similar markings occupy the base of the cliffs at Deany Steps, at Marble Arch, and immediately west of the mouth of the Sherbrook River where numerous echinoids (*Schizaster sphenoides* T. S. Hall, *Brissopsis tatei* T. S. Hall, *Maretia anomala* Duncan, *Eupatagus laubei* Duncan, &c.) and casts of *Turritella* sp. also occur. Balcombian clays similar to those occurring in the coastal sections north-west of Point Ronald, and equally rich in fossils, outcrop inland in small landslides (= Chapple's locality on the northern bank of Latrobe Creek, about half-a-mile from Princetown (9). At Deany Steps, (?) algal clays are exposed for at least forty feet above sea level. They overlie a narrow band of limestone, which forms the wave-cut platform here. This limestone is harder than the limestones higher up in the cliffs and is a pure form composed principally of minute foraminifera, gasteropods and occasional ostracods At Marble Arch, (?) algal clays also occur for forty feet upwards from the cliff base. They are overlain by friable limestones nearly white in colour, which represent leached portions of the younger limestone beds of the area. These beds contain Balcombian foraminifera.

Resting upon the (?) algal clays are shelly calcareous clays, argillaceous limestones and purer forms of soft and friable limestones (see upper part of Sentinel Rock in Plate II., fig. 2), which are only accessible in a few localities along the coastline, as at Rutledge's Creek, mouth of the Sherbrook River, the Amphitheatre, Deany Steps, London Bridge and Marble Arch. Because of the inaccessible nature of the intervening portions of the cliff sections, little can be said of the detailed characters of the sediments, but distant observations from the tops of the cliffs indicate no apparent variation in their nature from place to place. A detailed study of the more readily, but limited, accessible portions is, therefore, regarded as being sufficiently representative of the upper beds in general. Along portions of the coastline, fallen blocks from the higher parts of the vertical cliffs provide examples of fossils unrecorded from other localities in this part of the area. Thus, an example of *Paradoxechinus* was obtained from a fallen limestone block on Gibson's Beach. The stalk-eyed crab, *Ommatocarcinus corioensis* (Cresswell), which had previously been found at Two Mile Bay, associated with a few brachiopods and mud-haunting spatangoids (15), is a relatively common species in the (?) Balcombian limestones of the Port Campbell cliffs, occurring at Beacon Steps, Sherbrook River beach cliffs, Amphitheatre, Gravel Point, Rutledge's Creek, London Bridge, cliffs opposite Sentinel Rock, &c., where they have been collected both in situ and from fallen blocks. The soft basal clays containing (?) algal remains at the base of the cliffs in other accessible parts of the area are represented in the cliffs of Loch Ard Gorge by a dark indurated clayey rock containing examples of *Brissopsis tatei* T. S. Hall and "*Magellania.*" Above this is a band of similar rock with patches containing abundant remains of *Ditrupa*, 15 to 20 feet above sea level. The lower beds in the cliffs are here overlain by limestones and argillaceous limestones.

At the Rutledge's Creek coastal section (= Wilkinson's No. 10 locality), where the beds are stratigraphically higher than the Gellibrand Clays by some 100 to 150 feet or more, a whitish to cream coloured limestone forming the wave-cut platform occurs in the base of the cliffs for up to about 6 feet above sea level. It is overlain by 10 to 15 feet of calcareous clay rich in molluscan and foraminiferal remains, and also containing numerous brachiopods, a few polyzoans, scaphopods, echinoids and cetacean bone fragments. Dr. F. A. Singleton has identified *Eotrigonia semiundulata* (Jenkins) and *Neotrigonia acuticostata* (McCoy) from this calcareous clay; both of these forms occur at the same level in a prominent storm notch (Pl. II., fig. 1), but elsewhere in Victoria they usually, though not always, occur on different horizons in the Tertiary series. Mr. O. P. Singleton has identified *Nototrivia subtilis* Schilder and *Ellatrivia minima*

(T. Woods), both of which are Balcombian species, from the Rutledge's Creek clay. The macro- and micro-fossil organisms from this clay are generally comparable with the fossil assemblage of the Gellibrand Clays (Balcombian), the main differences being the greater prominence of large cowries in the Gellibrand Clays, and the presence of the two forms of Trigonia and a few additional genera (usually indicating a younger age elsewhere in Victoria), in the Rutledge's Creek Clays. The calcareous clays at the Rutledge's Creek coastal section thus appear to constitute a slightly later phase than the typically Balcombian Gellibrand Clays. Above the calcareous clay band at Rutledge's Creek occur 10 to 15 feet of argillaceous limestone, then 20 feet of friable limestone, followed by 50 feet of soft, but purer forms of limestone (see Table 3). The Tertiary series here is covered by a veneer of post-Miocene clay deposits about 5-10 feet thick. The limestone beds in the upper parts of the cliffs are not as rich in fossils as the calcareous clays, but contain a few Balcombian species of foraminifera and scattered examples of *Brissopsis tatei* T. S. Hall, "*Magellania*," *Serripecten yahlensis semilaevis* (T. Woods), polyzoa and crab remains. Additional fossil genera from the limestone beds of other parts of the Port Campbell district are the large echinoid *Linthia compressa* (Duncan), found high up in the cliffs at the Grotto, *Lovenia forbesi* (T. Woods) in the upper parts of the cliffs at the Amphitheatre, Broken Head, Sherbrook River beach, Castle Rock, Point Hesse and Peterborough (Wilkinson's No. 11 locality), *Clypeaster cf. gippslandicus* McCoy at 45 feet above sea level at Hennessy Steps, at 15 feet above sea level on the west bank at the mouth of Rutledge's Creek, and 54 feet above sea level in a prominent notch at the Amphitheatre. One example of *Isurus* was found in the clays of post-Miocene age on the Tertiary limestones at Gravel Point; this form has a matrix of limestone identical with the limestone of the underlying Tertiary beds, and is therefore a remanié fossil derived from the Tertiary rocks.

The limestones of the Port Campbell coastal sections extend inland for some considerable distance. Outcrops of limestone and calcareous clays which occur at greater heights at Timboon, Curdie Vale, Jancourt and elsewhere contain foraminiferal assemblages similar to those in the Port Campbell limestones and clays. *Ellatrivia minima torquayensis* Schilder has been identified by Mr. O. P. Singleton from a specimen in the T. S. Hall collection collected inland from clays near the Port Campbell cheese factory. The prominent harder patches and sheets in the more friable limestones exposed in the coastal and inland sections sometimes contain similar fossils to those in the limestones. Dense, fine-grained portions are composed of echinoid spines and minute foraminifera, included in a dense calcareous base

stained in parts by limonite, and containing a few angular quartz grains. Such portions in the limestones are of concretionary character, and are partly of secondary origin.

At the Amphitheatre, one-half to three-quarters of a mile west of the Rutledge's Creek coastal section, the lower 30-35 feet of the cliff is inaccessible, but in the hanging valley of Ingle's Creek, bluish-grey coloured clays with "*Magellania*" underlie a hard calcareous band. This hard band is some six feet or so above the creek bed. Immediately underneath it *Ditrupa* is common. Above the hard calcareous band are some 65 feet of Tertiary sediments, starting with argillaceous limestone, from which *Schizaster sphenoides* T. S. Hall was obtained, and followed by a narrow bed of limestone, rich in comminuted shell fragments as well as complete shells. Overlying this is a layer showing well-developed chemical banding by iron oxide and a few fossils; this in turn is overlain by limestones with a calcareous clay band containing *Scutellina patella* Tate, *Brissopsis tatei* T. S. Hall, polyzoans, *Magellania garibaldiana* (Duncan), *Ostrea* sp., *Serripecten yahlensis semilævis* (T. Woods), *Cucullaea corioensis* McCoy, *Volutospina antiscalaris* (McCoy), *Dentalium mantelli* Zittel, &c. These are abundant on the east side of the Amphitheatre, in the face of a well-marked notch some six feet in height from floor to roof. The foraminiferal assemblage and many of the macro-fossils in this notch, which is 54 feet above sea level, are similar to those in the notch some ten feet or so above sea level at the Rutledge's Creek coastal sction. The difference in height in these two instances is due to either faulting or local warping of the Tertiary sediments. Above the calcareous clay band at the Amphitheatre are about 50 feet of argillaceous and purer forms of limestones. They contain sporadic occurrences of fossil species similar to those in the notch. Among these higher beds is another band rich in *Ditrupa*, overlain by a bed of limestone with occasional small pellets of glauconite. Ten to 15 feet of post-Miocene clays and Recent soils cap the Tertiary deposits at this locality.

The height of the lower Ditrupa beds at the Amphitheatre is 45 feet above sea level, the same height as occurrences at the top of the third storm bench above sea level at Hennessy Steps (a few yards east of Broken Head), where associated fossil forms are numerous branching and disc-shaped polyzoans and occasional echinoids. Chapman (3, p. 30) and Chapman and Crespin (5) attached some importance to the occurrence of *Ditrupa* in Victoria, stating that it was typical of Victorian Janjukian beds. Since the Ditrupa beds in the Port Campbell district are stratigraphically higher than the Gellibrand Clays, which are of Balcombian age (29), then the Janjukian beds would, on these views, be above the Balcombian beds. Singleton, however,

places the Balcombian above the Janjukian (29), and this is the condition near Princetown. Accordingly, the Ditrupa beds must be late Balcombian or younger because the typical Balcombian deposits exposed in the coastal sections of this region are considerably lower on the stratigraphical scale, occurring as dipping beds some miles further to the south-east, at the locality three miles north-west of the mouth of the Gellibrand River. Ditrupa cannot be regarded, therefore, as typically Janjukian in this area. Determinations of the foraminifera by Mr. W. J. Parr (see appendix) indicate that the majority of the Tertiary beds in the Port Campbell district, north-west and west of the Gellibrand River belong to the Miocene (Balcombian) era of the Tertiary division. Preliminary examination of the molluscs by Dr. F. A. Singleton indicates that the Gellibrand Clays are Balcombian, while stratigraphically higher clays at Rutledge's Creek have a mixed fauna, principally Balcombian, but with some forms suggesting Cheltenhamian affinities.

## Post-Miocene.

Clays of still younger age than the Miocene deposits of the district have been designated post-Miocene clays. They rest upon the upper limestones of the Tertiary series, varying in thickness from 2 to 20 feet. The contact with the underlying Miocene beds appears to be in the nature of a disconformity, with an apparent old erosion surface in the Tertiary rocks, formed parallel to the more or less horizontal bedding planes in the Tertiary sediments (see Pl. II., fig. 3). This, however, is not the true explanation, as the post-Miocene clays are most likely residual clays formed from the dissolution of younger horizons of the Tertiary limestones. These clays are yellow, red, brown and bluish-grey in colour; the variable colouration arising from different degrees of iron staining and leaching. They are compact with rare, well-rounded pebbles of reef quartz and quartzite, occasional aboriginal flints, and a certain amount of sand. They are frequently associated with abundantly developed buckshot gravel which occurs both at the surface, and at depths of 18 inches below the top of the clays. Occasional mounds of massive hydrous iron oxide are also associated with these clays at Gravel Point, Point Hesse and elsewhere. The iron oxide in such deposits was probably derived from iron salts that are present in most natural waters; it is doubtful whether sufficient could have heen derived from the Tertiary sediments in the immediate neighbourhood. The post-Miocene clays contain remanié fossils derived from the Miocene limestones, and also occasional hard, nodular fragments of the limestone. The remanié fossils occur as fragments of *Serripecten, Magellania, Cellepora,* &c., which show signs of destruction by solution. The clays were, therefore, formed as residual deposits from the solution and weathering

of the higher members of the Miocene limestone series. This conclusion is supported by the fact that the limestones contain a certain percentage of clay constituents in their composition (see Table 3).

The post-Miocene clays nowhere come into contact with the Pleistocene dune limestone, consequently their age relationships can only be inferred from physiographical evidence The past topography of the area was such that it appears likely that the post-Miocene clays had commenced to form before the ancestor of the Gellibrand River had eroded the wide valley in the Tertiary rocks, in which the Pleistocene dune limestone was ultimately deposited.

## Pleistocene.

The Pleistocene dune limestone was deposited in at least three main stages. Murray records red sand beds about one or two feet thick between the calcareous sandstone beds, separating the series into layers 15, 40 and 50 feet thick, respectively (23, p. 129). Such interbedded material has come to be regarded in Victoria as representative of fossil soil horizons. The red bands are of limited lateral extent, occurring for no more than 200 yards in the Dune Cliffs at Princetown Where they cut out, distinct breaks, representing bedding planes, continue between layers containing narrow bands (Pl. II., fig. 5), dipping at different angles (maximum 30°). As many as six such breaks are present in the river cliffs on the west bank of the Gellibrand River, about 300 yards from the river mouth, so there may be this number of depositional stages in the Pleistocene dune limestone. These stages are probably due to various eustatic changes of sea level during the Pleistocene Ice Age. The dune limestone shows the usual marked current bedding characteristic of similar rocks elsewhere in Victoria. It consists principally of comminuted shell waste, loosely cemented by secondary calcium carbonate, and is consequently of a porous nature. The degree of shell comminution and grain sorting suggests that these deposits were developed on shell banks and shelly beaches, where changes in the strength and direction of marine currents were pronounced. Occasional secondary hard bands of limestone, one to three inches thick, have been precipitated along some of the bedding planes, and small patches of recently formed red soil (terra rossa) are associated with the dune limestone west of a small quarry near Princetown. These recent patches of red soil represent the insoluble residue of clay and other mineral matter, left behind at the surface in depressions, after solution of the dune limestone. They are, therefore, comparable in origin with the red sandy beds intercalated within the dune limestone, and with the clays of post-Miocene age overlying the Miocene limestones of the district.

## Holocene.

Recent deposits in the Port Campbell coastal area are represented by sand dunes, sand ridges, beach sands, and loose rudaceous deposits of angular character. The latter are formed from the older rock types, and consist of fallen blocks of Tertiary clays and limestones in some parts, Pleistocene dune limestone in others, and in parts they contain fragments of ironstone. The larger, angular fragments are set in a matrix composed partly of material derived from the post-Miocene clays, partly of smaller constituents from the Tertiary rocks. These deposits form large talus cones at the cliff bases, and perched talus cones on ledges situated at various heights up the vertical cliff faces Patches of duricrust occur on non-vegetated portions of some of the Recent sand dunes, such as near the mouth of the Sherbrook River, and immediately east of Glenample Steps. Recent marine silts and sands, in part fossiliferous (23), occur along the lower reaches of some of the larger streams in the area, mixed with river-borne silts, sands and gravels. A well sunk through the floor of Port Campbell Creek (near the tennis courts) by a local resident, Mr John Hennessy, revealed first 18 feet of Recent sands, and then two feet of shelly clays; the well ended in sands a short distance below the clay, and the sands immediately above the clay bed are said to have contained ti-tree remains. Recent clays and a bed of conglomerate two feet thick, overlain by clay, dune sands and kitchen midden materials, have infilled a small valley east of the mouth of the Sherbrook River. The pebbles in the conglomerate consist almost entirely of rounded fragments derived locally from the harder Tertiary limestone beds, and a few rounded ironstone fragments. This conglomerate is 12 feet above sea level and represents an old storm beach. It has been partially scoured out by recent marine activity.

The following table (Table 2) is a summary of the sequence of events in the history of the area as interpreted from several accessible cliff sections of varying height. It includes estimates of the thicknesses of the beds, wherever obtainable. The sequence was determined from a traverse in the direction of dip along the coastal sections, i.e., from S.E. to N.W. and W.

Table 2.

Geological Sequence in the Port Campbell Coastal District.

(Based on Wilkinson's and the author's observations.)

1. Jurassic, Calcareous felspathic sandstones (arkoses) and mudstones with nodules, carbonised wood and occasional small patches of coal. Occurs in the coastal sections from Pebble Point to Moonlight Head.

2. Time Interval Extending Through the Cretaceous.

3. EOCENE. (*a*) Grits, massive ironstones and sandy ironstones with quartz pebbles and fragments of Jurrassic rocks. Fossiliferous beds with *Cucullaea psephea, Lahillia australica, Limopsis* sp., *Nuculana paucigradata, Dentalium gracilicostatum, Aturoidea distans, Nautilus victorianus, Callianassa* sp., Shark's teeth and fossil wood.—50 feet.

(*b*) Black and greenish-coloured clay with sulphides, copiapite, a few quartz pebbles and occasional shelly fossils. In middle of clay beds, felspathic sandstone bands from east to west, (i) a band with echinoid and pelecypod casts, (ii) a band with *Turritella* sp. and *Ditrupa,* (iii) a band with *Odontaspis, Cycloseris* and *Trochocyathus.*—125 feet and over.

(*c*) Red and yellow sandy beds, ferruginous and non-fossiliferous.—35 feet.

(*d*) Black carbonaceous clays and sandy clays, with gypsum and copiapite in parts.—40 feet.

(*c*) and (*d*) may possibly be of Oligocene age. The beds in this sequence comprise the dipping strata south-east of the mouth of the Gellibrand River, and include Wilkinson's Nos. 6, 7, and 8 localities (34). The deposits total some 250 feet in thickness, according to Wilkinson, but are probably nearer 1,000 feet thick (1) They occur in the coastal sections between the Gellibrand River and Pebble Point.

4. GAP IN SEQUENCE OF TERTIARY BEDS (DUE TO POST-MIOCENE EROSION) AND PROBABLY REPRESENTING OLIGOCENE TIME AREA OCCUPIED BY PLEISTOCENE DUNE LIMESTONE.

5. UPPER OLIGOCENE-MIOCENE (JANJUKIAN).

(i) *a.* Blue sandy clays with a few quartz pebbles, but no fossils.—7 feet.

*b.* Yellow, red and grey sandy clay, with no fossils.—20 feet.

These are west-dipping beds 40 chains north-west of the mouth of the Gellibrand River.

(ii) *a.* Ferruginous gritty sandstone.—15 feet.

*b* Ferruginous phosphatic conglomerate, with abundant fossils.—3-8 feet.

*c* Gritty limestone with corals, echinoids, polyzoa, pelecypods, &c.—15-20 feet.

*d* Fossiliferous clays —20 feet.

The beds in Section 5 (ii) dip westerly at low angles and occur 40-50 chains north-west of the mouth of the Gellibrand River. They comprise an older phase than the true Balcombian sediments, and appear to be Janjukian on the evidence of the shelly fossil content, but a transition phase between the Janjukian and the Balcombian from the evidence of the foraminifera.

6. MIOCENE (BALCOMBIAN).

Grey and blue coloured clays with a variable shelly fossil content and traces of bedding planes dipping westerly at 5 degrees, outcrop at intervals between localities 50 chains north-west and 3 miles north-west of the mouth of the Gellibrand River. At three miles north-west of the Gellibrand, the sequence is —

(*a*) Blue, stiff clay with many molluscs, corals, polyzoa, &c.—40 feet

(*b*) Yellowish calcareous clay with few fossils.—32 feet.

The total thickness of this series of sediments is calculated at about 650 feet, from the fact that they dip at 4-5 degrees and outcrop over a distance of two miles.

7. MIOCENE (? BALCOMBIAN).

Horizontal limestones and calcareous clays, 100 feet thick in some parts, up to 300 feet thick in other parts.

(i) *a.* Hard, yellowish to cream coloured limestone with few fossils.—6 feet.

*b.* Calcareous, bluish-grey coloured clay, rich in fossils. Argillaceous limestone with few fossils.—30 feet

*c* Yellow and whitish-coloured limestones with a few fossils.—54 feet,

The beds in 7 (i) occur at the Rutledge's Creek coastal section.

(ii) *a.* Bluish-grey coloured clays.—36 feet.

*b.* Argillaceous limestone, shelly limestone, richly fossiliferous calcareous clay, purer forms of limestone with some fossils.—65 feet.

The beds in 7 (ii) occur at the Amphitheatre.

(iii) *a.* Bluish grey coloured clays.—40 feet.
*b.* Argillaceous limestones, calcareous clays and purer forms of limestones.—200 feet.

The beds in 7 (iii) occur at Deany Steps.

The sequence of beds in 7 (i), 7 (ii), and 7 (iii) is generally similar in the cliffs from Castle Rock in the south-east to within half a mile of the Grotto in the west Variations in total thickness at each of the several cliff sections examined result from cliff height variations and local warping in parts.

(iv) Soft yellowish limestone with few fossils, resting on calcareous clays similar to those in 7 (i) *b* at the Rutledge's Creek coastal section.—30-40 feet.

The beds in 7 (iv) occur in the vicinity of Curdie's Inlet. The beds in 7 are younger phases of the Miocene beds. They are regarded as ?Balcombian, being stratigraphically higher than the Balcombian of the coastal sections 3 miles north-west of the Gellibrand River, and having a somewhat different fauna.

8. POST-MIOCENE. Red, brown, yellow and blue-grey sandy clays with remanié fossils. These extend along the tops of the cliff sections from Glenample Steps to the Grotto.—2-20 feet.

9. PLEISTOCENE. Dune limestones of the Gellibrand River area—Up to 300 feet.

10. RECENT—Unconsolidated dune sands, beach deposits, red soils, alluvium, duricrust, &c.

## Lithology and Mineralogy of the Sediments.

The lithological and mineralogical characteristics of the Jurassic and Eocene beds S.E. of the mouth of the Gellibrand River have been dealt with elsewhere (1).

(?) OLIGOCENE.

The sandy clay 30 chains N.W. of Point Ronald is a rather incoherent sediment which rapidly sludges in water. Seventy-one per cent. of the deposit consists of almost pure white quartz sand of even grade size, the grains being 0.2-0.8 mm. across. The quartz grains are well rounded, some are translucent, some are opaque, partly as a result of pitting by abrasion, very few are sub-angular or iron-stained. A small amount of andalusite and rare grains of both blue and brown tourmaline are present in addition to the minerals listed in Table 3. The ferruginous gritty sandstone from the cliff section half-a-mile north-west of the mouth of the Gellibrand River consists of rounded and angular quartz grains and limonite pellets with a few foraminifera, coral fragments, felspar grains, and quartzite fragments, set in a partly calcareous, partly ferruginous base. Similar materials occur in the matrix of the overlying ferruginous phosphatic conglomerate, which also includes matrix material identical with the overlying gritty limestone. The quartz grains in the limestone are up to 0.4 mm. long, opaque, white and translucent, and principally well-rounded. These are set in a calcareous base containing abundant micro-organisms—foraminifera, echinoid spines, &c., and fragments of polyzoa and shelly fossils. Fossil structures are partially replaced by ferruginous matter.

TABLE 3.—MINERAL COMPOSITIONS OF SOME PORT CAMPBELL ROCKS. (ROCK TYPES ARRANGED IN STRATIGRAPHICAL ORDER).

| | Rock. | Locality. | Percentage Soluble Fraction. | Percentage Clay. | Percentage Sand. | Rounded Quartz. | Angular to Sub-Angular Quartz. | Felspar | Mica | Glauconite (Oolitic and/or Foram. Casts) | Gypsum. | Ilmenite and/or Magnetite | Limonite. | Pyrite. | Tourmaline. | Cassiterite. | Zircon | Rutile. | Number. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Quaternary.* | Beach sand .. | Picnic Steps, 5 chains N. E. of Sentinel Rock | 70 | — | 30 | (X) | — | — | — | — | — | + | + | — | + | — | + | — | 1 |
| | Dune limestone .. | Quarry, 1 mile west of Princetown | 93 | tr. | 7 | (X) | + | + | — | — | — | + | + | — | + | — | + | + | 2 |
| | Duricrust .. .. | Mouth of Sherbrook River.. .. | 70·5 | 0·7 | 28·8 | (X) | + | — | — | — | — | + | + | — | + | + | + | — | 3 |
| | Post-Miocene clays .. | Broken Head .. .. .. | 6 | 66·5 | 27·5 | + | (X) | + | — | — | — | + | + | — | + | + | + | + | 4 |
| *M. Miocene.* | Soft limestone .. | 88′ above sea level, Rutledge's Beach | 91 | 8 | 1 | + | (X) | + | — | + | + | + | — | — | + | — | + | + | 5 |
| | Soft limestone .. | 73′ above sea level, Rutledge's Beach | 85 | 13·5 | 1·5 | + | (X) | + | — | + | — | + | + | — | + | — | + | — | 6 |
| | Friable limestone .. | 40′ above sea level, Rutledge's Beach | 86 | 14 | tr. | + | (X) | + | — | — | + | + | + | — | + | — | + | — | 7 |
| | Argillaceous limestone | 20′ above sea level, Rutledge's Beach | 79 | 21 | tr. | + | (X) | + | — | + | — | + | + | — | + | — | + | — | 8 |
| | Upper calcareous clay | 12′ above sea level, Rutledge's Beach | 53 | 47 | tr. | — | + | + | + | + | — | + | + | — | — | — | — | — | 9 |
| | Harder whitish limestone | Wave platform, Rutledge's Beach .. | 95 | 5 | tr. | — | + | — | + | — | — | + | — | — | — | — | + | — | 10 |
| | Harder grey limestone | Wave platform, Deany Steps . | 98 | 2 | tr. | — | + | — | — | — | — | + | — | — | — | — | — | — | 11 |
| | Lower calcareous clay | Beach section 2½–3 miles N.W. of Point Ronald | 36 | 64 | tr. | — | + | — | + | + | + | + | — | + | — | — | + | — | 12 |
| *L. Miocene.* | Lowest calcareous clay | 50 chains N.W. of Point Ronald .. | 37·5 | 62 | 0·5 | — | + | + | + | + | + | + | + | + | + | — | + | — | 13 |
| | Gritty limestone . | 50 chains N.W. of Point Ronald .. | 74·6 | 3·9 | 21·5 | (X) | + | + | + | + | — | + | + | — | + | — | + | + | 14 |
| | Sandy clay.. .. | ½ mile N.W. of Point Ronald .. | nil | 29 | 71 | (X) | + | — | — | — | — | + | + | — | + | — | + | + | 15 |

(x) = more common type of quartz grains.

Table 3 illustrates the acid solubility and mineral content of the more readily accessible Tertiary and Quaternary rocks from various localities along the coastal sections in the Port Campbell-Princetown district. The soluble fraction is composed principally of calcium carbonate, but small amounts of soluble iron compounds are also present. The sand fractions are composed principally of quartz. The heavy minerals are only represented by one or two grains of each species, except for limonite and ilmenite, which are more frequent. The felspar consists of plagioclase, microcline and orthoclase-perthite; the mica is present as a few flakes of brown and bleached biotite. Most of the mineral species were derived from the Jurassic arkoses and mudstones which formed the adjacent coastline at the time of deposition of the Middle Tertiary sediments. A peculiarity of some of the clays from the dipping Tertiary beds, 2$\frac{3}{4}$-3 miles north-west of the mouth of the Gellibrand River, is the ease and rapidity with which they sludge in water. The constituents of such clays are almost entirely under 0.2 mm. across.

MIOCENE.

In the lower calcareous clays from the cliff sections north-west of the Gellibrand, most of the soluble fraction is due to the abundance of foraminifera and polyzoa. Casts of some of these organisms remained after acid treatment. Quartz grains are few in number in these clays and are subangular in outline, with a maximum size of 0.1 mm. The clay content is greater in these rocks than in the other Tertiary lithological types, and is in part gypseous. Pyrite occurs as minute rounded pellets and rods, and as larger nodules up to 3 inches long.

The hard, grey-coloured limestone constituting the wave-cut platform at Deany Steps contains only a minute quantity of sand. Most of the small percentage of insoluble matter consists of minute clay particles. Small forms of foraminifera, polyzoa, molluscs and ostracods are set in a calcareous matrix in this limestone. The softer limestones in the cliffs at this locality contain occasional flints.

The limestone of the wave-cut platform at Rutledge's Creek has a somewhat greater percentage of insoluble matter (mainly clay) than that at Deany Steps, and is not of so compact a nature. The calcareous clay, 12 feet above sea level at Rutledge's Beach, is more calcareous than the stratigraphically lower calcareous clay three miles north-west of the mouth of the Gellibrand River, mainly because at the locality where it was sampled, a molluscan fauna is profusely developed. Above this clay, the beds in the cliffs at Rutledge's Beach grade into argillaceous limestone which becomes purer as the percentage of clay decreases in the limestones higher up the cliffs, where gypsum also appears in small quantities. The limestones forming the higher portions of the

cliffs in the Port Campbell district are fine-grained, the matrix being of clay grade in which complete, large and small fossil organisms are embedded.

A few glauconitic casts of foraminifera and other micro-organisms appear in the sand fraction of certain of the lime-stones and calcareous clays. In parts, the glauconite has been altered and replaced by limonite. A marked feature of portion of the limestone beds above the pronounced notch at the Amphi-theatre is the abundance of small dark-coloured spots of glau-conite, which proved to be pellets and micro-fossil casts.

### Post-Miocene.

The post-Miocene clays contain a small proportion of soluble carbonate. One grain of garnet and one grain of cyanite were seen in addition to the minerals listed in Table 3 (No. 4). The larger grains of quartz are well rounded, the smaller ones are sub-angular, and some of the quartz is of amethystine colour. The range in size of the quartz grains is 0.02 to 0.5 mm. across. The comparative clay-sand content for the post-Miocene clay and the Tertiary limestone from which the post-Miocene clay was derived is as follows:—

Tertiary Limestone: 9 of sand to 1 of clay
Post-Miocene Clay: 1 of sand to 3 of clay.

### Pleistocene.

The soluble fraction of the dune limestone in the Princetown district is comparable in amount with that for consolidated dune rock from Limestone Hill, Cashmore, in the Portland district (11). The dune limestone contains foraminiferal, polyzoal, echinoid and molluscan fragments. The sand grains are not as well rounded as in the beach sands of the district, and quartz is sometimes of amethystine colour, ranging in size from 0.05 to 1.25 mm. Numerous cavities occur between the sand grains in the rock, but there are areas where dense calcareous bands occur. Clear calcite frequently forms rims around some of the quartz grains, and infills cavities in some of the foraminifera and smaller forms of gasteropods. A thin section of the red sandy beds in the Pleistocene dune limestone reveals rounded quartz grains and fragmentary fossil organisms set in a limonite-stained cal-careous base.

### Recent.

In the duricrust from the sand dunes at the mouth of the Sher-brook River, quartz grains are abundant and well rounded. They are mainly colourless, but occasionally pink, and range in size from 0.2 to 1 mm. In the beach sands, the quartz grains are mostly well rounded, ranging in size from 0.4 to 1 mm., with the majority over 0.5 mm. across. It is therefore apparent that few of the quartz grains were derived from the post-Miocene

clays (0.02 to 0.5 mm.), most coming from the Jurassic sandstones and Pleistocene dune limestone. The soluble content of the beach sands is due to comminuted shell waste, echinoid spines, foraminifera, &c., many of which were derived from the fossiliferous Tertiary rocks in the cliffs.

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## Explanation of Plates.

PLATE II

*Fig.* 1.—Horizontal Miocene (?Balcombian) calcareous clays overlain by limestones, Rutledge's Creek coastal section. The apparent dip of the beds is due to the uneven surface of the beach. The notched clays at the cliff base are richly fossiliferous.

*Fig.* 2.—Conformable Miocene (?Balcombian) clays and limestones with low angle of dip in a south-westerly direction at Sentinel Rock (= the Haystack), 236 feet high,

*Fig.* 3.—Miocene (?Balcombian) strata with horizontal bedding planes marked by calcareous sheets and nodules of secondary origin, and overlain by post-Miocene clays, Castle Rock.

*Fig.* 4.—Fossiliferous Balcombian calcareous clays dipping 3 degrees south of west, and overlain by Miocene (Balcombian) limestones and Pleistocene dune limestone. Three miles north-west of the mouth of the Gellibrand River.

*Fig.* 5.—Pleistocene dune limestone showing current bedding Talus cone at base of dune limestone cliff, and unconsolidated calcareous dune sand (Recent) on terrace cut in Tertiary rocks 40 feet above sea level. Two and a half miles north-west of the mouth of the Gellibrand River.

*Fig.* 6.—Collapse structure—monoclinal fold caused by slumping of limestone beds into solution cave. Post-Miocene clays with buckshot gravel cap the Miocene limestones. Promontory on east side of the Grotto Bay.

*Fig.* 7.—Dark markings (? algal) in grey Balcombian clays. Three and a quarter miles north-west of the mouth of the Gellibrand River.

*Fig.* 8.—Intraformational contortion of Balcombian clays Three and a quarter miles north-west of the mouth of the Gellibrand River.

*Fig.* 9.—Cliffs of Balcombian clays partially masked by talus deposits of Pleistocene dune limestone. Two and a quarter miles north-west of the mouth of the Gellibrand River

*Fig.* 10.—Jointed Balcombian clays. Two and three-quarter miles north-west of the mouth of the Gellibrand River

*Fig.* 11.—Janjukian beds with a low westerly angle of dip Nodule bed below, and limestones, with ferruginous bands above. About 50 chains north-west of Point Ronald.

*Fig* 12.—Westerly dipping ? Oligocene, non-fossiliferous sandy clays, half a mile north west of Point Ronald.

## Appendix.

### *The Foraminifera of the Tertiary Beds Exposed in the Coastal Sections between the Mouth of the Gellibrand River and Curdie's Inlet.*

By W. J. PARR.

The material examined consisted of washings and selected specimens received from Mr. G. Baker, M.Sc., and four samples, one collected by Rev. George Cox, and the others by the writer. Details of these are as follows:—

SAMPLE. 1.—From gritty limestone, apparently largely bryozoal, ½ mile north-west of Point Ronald. (Coll. G. Baker, M.Sc.).

The material consists of bryozoa, with numerous well-developed foraminifera, 58 species of which were recognized. The commonest are *Dentalina soluta*, *Guttulina problema*, *Globulina* sp., *Sigmoidella* sp. aff. *kagaensis*, *Cassidulina subglobosa*, *Cibicides* sp. aff. *pseudoungerianus*, and *Dorothia* sp. aff. *parri*. These are found in the Balcombian and the Janjukian of Victoria. Two other species which occur have a more limited distribution, *Discorbis* sp. nov. (of *D. bertheloti* group) being, with the exception of records from Waurn Ponds and Birregurra, known only from the Janjukian of Torquay, in which it is common, while *Calcarina* sp. aff. *verriculata* occurs in the Janjukian limestones at the mouth of Spring Creek.

SAMPLE. 2.—Clays immediately overlying gritty limestone ½ mile north-west of Point Ronald. (Coll. G. Baker.)

The washings are rich in well-preserved foraminifera, of which 82 species were separated All of the more common forms in Sample 1 are present in addition to *Sigmomorphina chapmani* (described from the Miocene limestone of Batesford), *Bulimina* sp. nov. (common in Tertiary of Castle Cove), *Discorbis* sp. nov. (same species as in Sample 1), *Spiroloculina canaliculata, Cyclammina* sp. cf. *complanata, Liebusella antipodum* (common in Janjukian of Torquay, also noted from Tertiary of Lake Gnotuk), and *L. rudis* (only Victorian record is from Balcombian). The bryozoan, *Otoniella cupola*, var. *spiralis* is also present.

SAMPLE 3.—Selected foraminifera from clays in cliffs, west of "Curdie's Steps" about ¾ mile north-west of Point Ronald. (Coll. G. Baker.)

There are 22 species of foraminifera, the assemblage being a typically Balcombian one, including *Cibicides victoriensis* (very fine examples), *Ceratobulimina (Ceratocancris) hauerii*, var. *australis, Dorothia* sp. nov. aff. *karreri, Carpenteria proteiformis* and the usual miliolines.

SAMPLE 4.—Selected foraminifera from dipping clays, 2¾-3 miles north-west of Point Ronald (mouth of Gellibrand River). (Coll. G. Baker.)

There are 17 species of foraminifera, including *Cibicides victoriensis* (very typical), *Ceratobulimina (Ceratocancris) hauerii*, var. *australis*, and other Balcombian species.

SAMPLE 5.—Three miles north-west of mouth of Gellibrand River. (Coll. G. Baker.)

The washings consist principally of foraminifera with abundant *Globigerinae*. There are 58 species of foraminifera including *Uvigerina interrupta* (Balcombian, Recent), *Ehrenbergina* sp. nov. aff. *mestayeri* (Balc.), *Ceratobulimina (Ceratocancris) hauerii*, var. *australis* (Balc.), *Hofkerina semiornata* (Balc.), *Globigerinoides ruber* (common—the only previous Victorian Tertiary record is from the Miocene limestone of Batesford), *Globigerina dehiscens* (Balc.), and *Dorothia* sp. nov. aff. *karreri* (Balc.). There are also many examples of a peculiar form related to Jedlitchka's genus *Candorbulina*. This assemblage is undoubtedly Balcombian in age.

SAMPLE 6.—Clays from Gibson's Beach, 3½ miles north-west of mouth of Gellibrand River. (Coll. Rev. G. Cox.)

Forty-six species of foraminifera. All are Balcombian forms. The only noteworthy species is *Miniacina miniacea*, which is known from Balcombe Bay, the lower beds at Muddy Creek, and the Batesford limestone.

SAMPLE 7—Hard grey argillaceous limestone from about 80 feet above base of cliff, up pathway at Gibson's Steps. (Coll. W. J. Parr.)

Forty-two species of foraminifera were recognized. The only species of note are *Cibicides* sp. aff. *victoriensis* (a Balcombian form) *Ceratobulimina (Ceratocancris) hauerii*, var. *australis* (Balc., common), *Liebusella rudis* (Balc., large typical specimens common), and *Textularia* sp. nov. aff. *carinata*. The age is Balcombian.

SAMPLE 8.—Selected foraminifera and washings from clay at 12 feet above sea level, east side of mouth of Rutledge's Creek. (Coll. G. Baker.) Other material collected by the writer from the same bed was also examined.

This material is rich in species of foraminifera, 138 being recognized. They include *Sigmomorphina* spp., *Bolivinella* sp. nov., *Pavonina triformis, Discorbis papillata* (Balc.), *D.* sp. aff. *corrugata* (previously known only from lower beds, Muddy Creek), *Cancris intermedia* (Balc.), *Cibicides* sp. aff. *victoriensis, Elphidium parri, E. subinflatum* (Batesford and lower beds, Muddy Creek), *Planispirinella exigua* (Balc. and Recent), *Biloculinella angusta* (Balc., and Janjukian of Torquay), *Textularia* sp. nov. aff. *carinata, Gaudryina collinsi* (Western Beach, Geelong, apparently Balcombian), *Carpenteria rotaliformis,* and *Dorothia* sp. nov. aff. *karreri* (Balc.) The bryozoan, *Otoniella cupola,* var *spiralis,* and the annelid, *Ditrupa,* also occur.

Sample 9.—Washings from argillaceous limestone at 20 feet above sea-level, east side of mouth of Rutledge's Creek. (Coll. G. Baker.)

There are fourteen species of foraminifera, the only species at all common being *Cibicides* sp. aff. *pseudoungerianus, C. victoriensis* (Balc.), *Orbulina universa,* and *Textularia* sp. nov. aff. *carinata.* Fragments of the tubes of the worm *Ditrupa* and the coral *Mopsea* also occur

Sample 10.—Washings from friable limestone at 40 feet above sea level, east side of mouth of Rutledge's Creek. (Coll. G. Baker.)

There are 25 species of foraminifera, the predominant forms being the same as in Sample 6. Spines of a spatangoid sea urchin are common and there are a few bryozoans.

Sample 11.—Washings from soft limestone at 73 feet above sea level, east side of mouth of Rutledge's Creek. (Coll. G. Baker.)

Thirty-one species of foraminifera were recognized, including *Cibicides* sp. aff. *pseudoungerianus, C. victoriensis, Globorotalia dehiscens,* and a new, large, smooth species of *Bolivina.*

The samples from the mouth of Rutledge's Creek represent two facies of the Balcombian, one argillaceous from low down in the cliffs, and the other calcareous from the upper portions of the cliffs

Sample 12.—Selected foraminifera from Notch, 54 feet above sea level, Amphitheatre, about ½ mile west of mouth of Rutledge's Creek. (Coll. G. Baker.)

Thirty-one species of foraminifera. They include *Sigmoidella kagaensis, Cancris intermedia, Cibicides* sp. nov. (occurs also at mouth of Rutledge's Creek, 12 feet above sea level), *C.* sp. cf. *victoriensis, Planispirinella exigua,* and *Dorothia* sp. nov. aff. *karreri.* The age is Balcombian

Sample 13.—Washings from blue-grey calcareous clay at base of cliffs, Deany Steps. (Coll. G. Baker.)

There are 43 species of foraminifera, including *Ceratobulimina* (*Ceratocancris*) *haueri*, var. *australis, Epistomina elegans* (common), 3 spp. of *Globorotalia, Textularia* sp. nov. aff. *carinata* (common), and *Martinottiella bradyana.* A Balcombian age is indicated.

Sample 14.—Limestone from base of cliffs just west of mouth of Curdie's Inlet. (Coll. W. J. Parr.)

Thirty-nine species of foraminifera. The commonest forms are *Liebusella rudis, Sigmoidella* sp. aff. *kagaensis,* and *Elphidium parri.* The species are all found in the Balcombian.

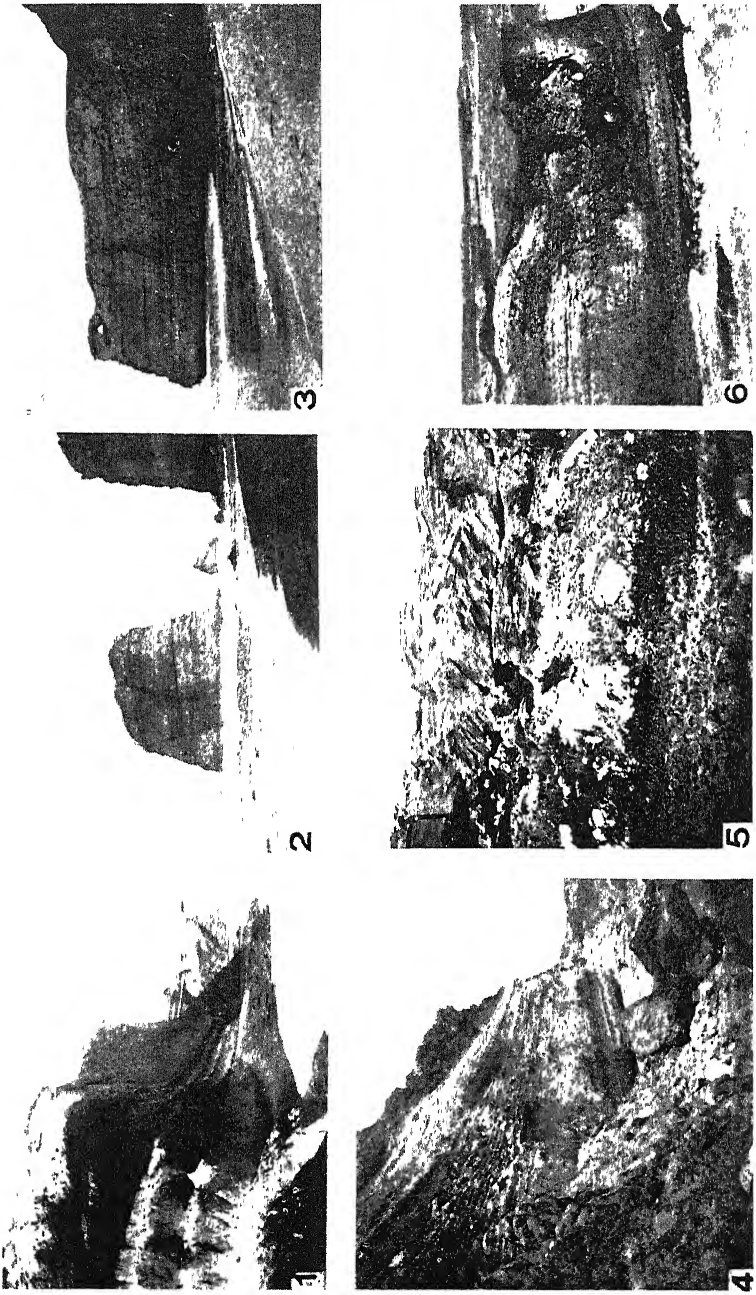
THE EVIDENCE OF THE FORAMINIFERA AS TO THE AGE OF THE DEPOSITS.

To sum up, it may be stated that, with the exception of Samples 1 and 2 from ½ mile north-west of the mouth of the Gellibrand River, the foraminifera in the samples examined indicate that the age of the beds from which they were collected is younger than the Janjukian and older than the Cheltenhamian. Some of the species are new, but the remainder in Samples 3 to 14 are forms which, according to the present state of our knowledge, are restricted to the Balcombian or are best represented in beds of that age. There are none of the restricted species of either the Janjukian or of the Cheltenhamian or higher beds. The larger foraminifera such as *Operculina, Amphistegina,* or *Lepidocyclina,* have not been found. *Hofkerina* and *Carpenteria,* with which they are generally associated, have, however, been met with and, as both are typically Balcombian in their occurrence, the absence of the other genera mentioned can be explained by the presence of conditions unfavorable to their existence.

Samples 1 and 2, from ½ mile north-west of Point Ronald, appear to be the oldest beds exposed, as the foraminifera include several species indicating a lower horizon than typical Balcombian. These species are referred to in the notes on the samples.

The term "Balcombian" as here used embraces the Batesfordian, as it has not been possible in the Port Campbell area to distinguish these two stages as defined by Dr. F. A. Singleton (29).

The total number of species of foraminifera recognized was 232.

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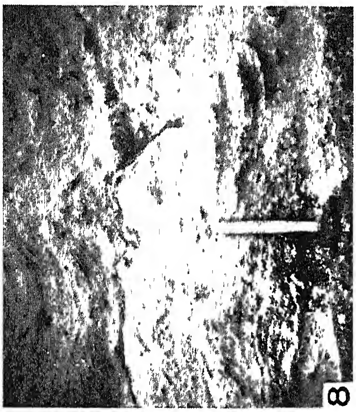
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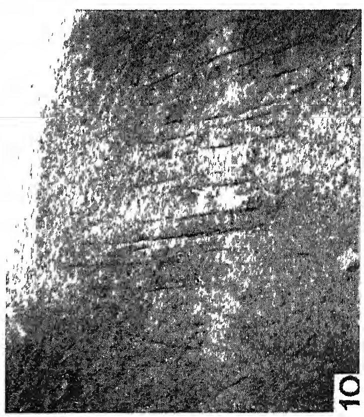
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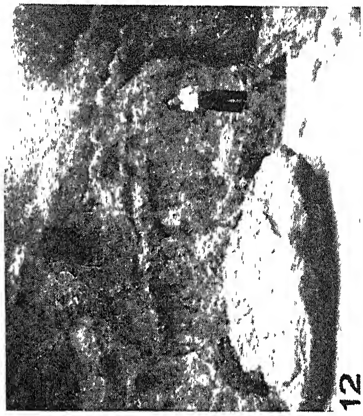
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[PROC. ROY. SOC. VICTORIA, **56** (N.S.), Pt. I., 1944.]

# ART VI.—*Symptoms of Copper Deficiency in Flax.*

By C. R. MILLIKAN, M Agr Sc.

[Read 8th August, 1943; issued separately 1st August, 1944.]


## Abstract.

Wheat and flax plants in copper deficient water cultures developed severe symptoms of malnutrition. The wheat symptoms were identical with those of "reclamation disease." The flax plants showed a general chlorosis, and a somewhat rosetted appearance of the top of the plant due to shortening of the internodes. The leaves became puckered, slightly inrolled along the edges, and very twisted Growth finally ceased, and the plants commenced to die from the top.


## Introduction.

Owing to the difficulty experienced by early workers in removing small traces of copper from their nutrient solutions, the essential nature of this element for plant growth was not demonstrated until comparatively recently. Sommer (1931) was the first to show that the absence of copper in the nutrient solution resulted in a very appreciable reduction in the growth of flax, sunflowers and tomatoes; but she did not describe the symptoms manifested by the copper deficient plants.

More recently other workers, notably Brandenburg (1935), van Schreven (1936) Arnd and Hoffmann (1937), Stout and Arnon (1939) and Piper (1940, 1942) have confirmed the findings of Sommer and have described the symptoms of copper deficiency in a wide variety of plants. However, before the most recent paper of Piper, there had apparently been no description of copper deficiency symptoms in flax. In view of this in 1941 and 1942, Free Gallipoli wheat plants and Liral Crown flax plants were grown in copper deficient water cultures at the Plant Research Laboratory, Burnley, primarily with the object of determining the symptoms of copper deficiency in flax. Wheat was included in the experiment, as the symptoms of copper deficiency in cereals were well known and, their occurrence in the cultures would afford confirmation of the degree to which the copper had been eliminated from the nutrient solution.

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## Method.

The nutrient solution used was that of Arnon (1938), the composition of which was as follows:—

| | | |
|---|---|---|
| Potassium Phosphate .. | $K_2HPO_4$ | .. 0.001Molar |
| Potassium Nitrate .. | $KNO_3$ | .. 0.006Molar |
| Calcium Nitrate .. | $Ca(NO_3)_2 \cdot 4H_2O$ | .. 0.004Molar |
| Magnesium Sulphate .. | $MgSO_4 \cdot 7H_2O$ | .. 0.002Molar |
| Boron as Boric Acid .. | $H_3BO_3$ | .. 0·5 parts per million |
| Manganese as Manganese Sulphate .. .. | $MnSO_4 \cdot 4H_2O$ | .. 0·5 parts per million |
| Zinc as Zinc Sulphate .. | $ZnSO_4 \cdot 7H_2O$ | .. 0·05 parts per million |
| Copper as Copper Sulphate .. .. | $CuSO_4 \cdot 5H_2O$ | .. 0·02 parts per million |
| Vanadium as Ammonium Vanadate .. .. | $NH_4VO_3$ | .. 0·01 parts per million |
| Chromium as Chrome Alum . | $Cr_2K_2(SO_4)_4 \cdot 24H_2O$ | .. 0·01 parts per million |
| Nickel as Nickel Sulphate . | $NiSO_4 \cdot 6H_2O$ | .. 0·01 parts per million |
| Cobalt as Cobalt Nitrate | $Co(NO_3)_2 \cdot 6H_2O$ | .. 0·01 parts per million |
| Tungsten as Sodium Tungstate . .. | $Na_2WO_4 \cdot 2H_2O$ | .. 0·01 parts per million |
| Molybdenum as Ammonium Molybdate .. | $(NH_4)_2MoO_4$ | .. 0·01 parts per million |

An iron solution containing 0.5 per cent. $FeSO_4$ + 0.4 per cent. tartaric acid was added twice weekly at the rate of 0.6 ml. per litre of culture solution When the plants were a few weeks old, this solution was added once a week. All these elements with the exception of copper were added to the copper deficient solutions. Every three-four weeks the old culture solutions were discarded and were replaced by fresh solution.

Molar stock solutions of the main constituents were purified by autoclaving with calcium carbonate in accordance with Stout and Arnon's (1939) modification of Steinberg's (1935) technique. After purification these stock solutions were tested by the dithizone test described by Stout and Arnon and found to contain less than 10 parts per billion of all metal impurities which react with dithizone. Double distilled water produced by pyrex glass stills was used to make up all solutions. The dithizone test indicated that this water contained approximately 1 part per billion of metal impurities Stout and Arnon have shown that degrees of purity of the order of those outlined above are satisfactory for demonstrating copper deficiency symptoms in plants. All glassware was cleaned with 1 : 1 hydrochloric acid and rinsed with distilled water before use.

The plants were grown in two litre pyrex glass beakers blackened on the outside by a coat of gold size followed by two coats of black blackboard paint.

Plaster of Paris tops soaked in paraffin were used to cover the beakers and support the plants. The wheat and flax seeds were germinated in acid-washed sand, and were transferred to the beakers as soon as they could be conveniently handled. Four wheat and four flax plants were grown in the same beaker.

## Results.

The following are the symptoms of copper deficiency which developed :—

WHEAT.

The first symptoms of copper deficiency appeared approximately three to four weeks after setting up the cultures. The plants were not as tall as the controls, a slight, general chlorosis became evident, and the youngest leaves were slow in unrolling The tips and distal edges of subsequently-formed leaves became markedly chlorotic and soon withered and died without unrolling (Pl. IV. fig. 1). While some secondary tillers were produced, the plants made very little further growth, with the result that no elongation or head formation occurred. The final height of the plants was approximately one foot, while the plants growing in the complete solution were over four feet high at the end of the experiment (Pl. IV. fig. 2). With the addition of small amounts of copper to wheat and oats growing in water cultures, Piper (1940, 1942) has shown that sterile heads may be produced. It was evident that the symptoms exhibited by the wheat plants growing in the copper deficient solutions were identical with those of "reclamation disease" described by other workers.

FLAX.

The flax plants grew normally for approximately four weeks, after which time growth became very retarded. The internodes between leaves produced subsequently were short, giving the top of the plant a somewhat rosetted appearance. These new leaves were much smaller than the controls and noticeably paler green in color than normal. They became puckered, slightly in-rolled along the edges, and very twisted (Pl. IV., fig. 3). The stems of the plants also showed some twisting. Later the leaves in the middle portion of the stem developed a dark, greyish-green, semi-transparent discolouration at the tips. These leaves soon drooped and withered and died from the tips downwards. The lowest leaves, on the other hand, remained apparently normal. Meanwhile, secondary shoots were sent out from the bottom, but soon became chlorotic with small twisted leaves. Finally growth ceased and the plants commenced to die from the tops.

Sommer (1931) and Piper (1942) have shown that, in the absence of copper, flax plants make very restricted growth. The symptoms of copper deficiency in flax, described by Piper, are similar to those set out above, with the exception that no twisting of the leaves was reported.

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## Description of Plate.

PLATE IV.

Fig. 1. Wheat leaves showing "wither tip" and inrolling characteristic of copper deficiency

Fig. 2. Water culture experiment with wheat and flax, showing the marked reduction in growth resulting from a deficiency of copper

Fig 3. Copper deficiency symptoms in flax. Left: Control. Right. Copper deficient plant showing marked reduction in growth, general chlorosis, and inrolling and twisting of leaves.

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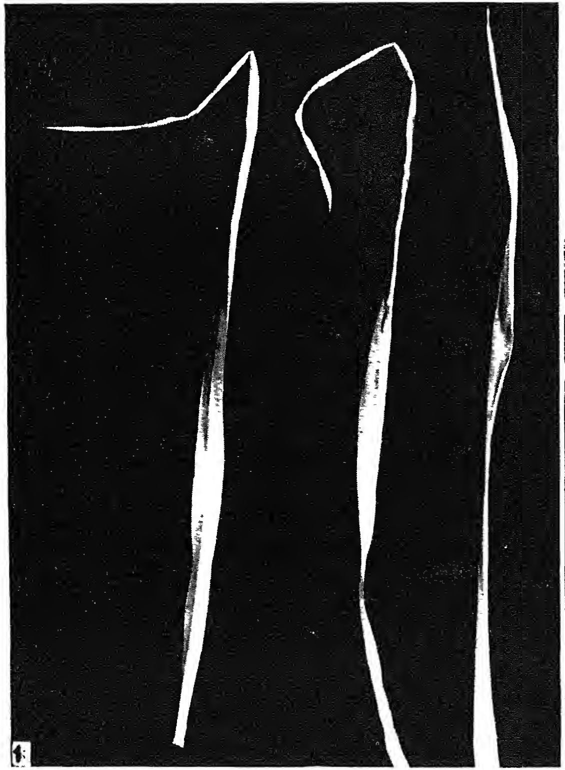

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[PROC. ROY. SOC. VICTORIA, 56 (N.S.), PT. II., 1945.]

# ART VII.—*Records of Plant Remains from the Upper Silurian and Early Devonian Rocks of Victoria.*

By ISABEL C. COOKSON, D.Sc.

[Read 11th November, 1943; issued separately 30th June, 1945]

In the period that has elapsed since 1935 when my last paper on Victorian Palaeozoic plants was published, further collections have been made from several hitherto unknown localities in the same stratigraphical series. These specimens were put aside pending the discovery of further examples which, it was hoped, might give more detailed information regarding the morphology of our early plant types. However, in order to facilitate the work of geologists interested in Palaeozoic stratigraphy, it has been suggested that the genera found at these new localities should be put on record now. This is therefore done below and for the sake of completeness, lists of plant remains from previously recorded outcrops are included. The botanical discussion of morphological details is being left until a later time.

Owing to the incompleteness of some specimens, a final determination cannot be made. The letters cf. before a species name denotes that the fossils are most likely referable to the species given.

I am indebted to Mr. W. Baragwanath and Rev. E. D. Gill, B.A., B.D., for information regarding some of the localities mentioned.

YEA—ALEXANDRA DISTRICT.

Killingworth-road, Yea. ¼ mile from Yea to Molesworth-road. Geol. Surv. loc. 14 (10, 5).

*Baragwanathia longifolia.*

cf. *Hostimella* sp.

Brackley's Cutting, Yea, to Cheviot-road, south of turn off Yea to Mansfield-road. Geol. Surv. loc. 4 (4, 5).

*Baragwanathia longifolia.*

Gobur, near allotments 9 and 10, east of township site. Geol. Surv. loc. 19 (5).

*Baragwanathia longifolia.*

Railway cutting, near Alexandra, between 99¼ and 99½ miles from Melbourne. Geol. Surv. loc. 9 (5, 10).

*Baragwanathia longifolia.*

First railway cutting out of Alexandra railway station. Geol. Surv. loc. 5 (5, 10).

*Baragwanathia longifolia.*

Mount Pleasant, $1\frac{1}{4}$ miles from Alexandra on the old road to Thornton (1).

*Pachytheca* sp.
*Zosterophyllum australianum.*
cf. *Hostimella* sp.
*Hedeia corymbosa.*
cf. *Yarravia*
cf. *Baragwanathia longifolia.*
"*Pinnately branched axes*".
"*Stems with small spirally arranged elevations*".
"*Circinately coiled tips*".

Hall's Flat-road—cutting on road from Alexandra to Hall's Flat, about one mile from the former (1).

*Zosterophyllum australianum.*
"*Pinnately branched axes*".

GAFFNEY'S CREEK—WOOD'S POINT DISTRICT.

Gaffney's Creek, road cutting near Police station (8).

cf. *Hostimella* sp.

Wood's Point, road to Comet Mine (9).

*Zosterophyllum australianum.*
cf. *Hostimella* sp.
"*Stems with small spirally arranged elevations or depressions*" (9) cf. Mt. Pleasant, Alexandra (1).

Indeterminate plant fragments have been collected from outcrops on the road from Gaffney's Creek to Wood's Point.

ENOCH'S POINT DISTRICT (6).

Cable's Creek, a western tributary of Big River south-west of Enoch's Point.

*Baragwanathia longifolia* (6, 8).

Enoch's Creek, east of township of Enoch's Point (6).

*Baragwanathia longifolia.*

WOOD'S POINT—WARBURTON DISTRICT.

Quarry on Yarra Track, about 20 miles east of "McVeighs" (3).

*Baragwanathia longifolia.*

Quarry on Yarra Track, about 19 miles east of "McVeighs" (10, 4, 3).

*Baragwanathia longifolia.*
*Yarravia oblonga.*
*Yarravia subsphaerica.*
cf. *Hostimella* sp.

Quarry on Yarra Track, about 18 miles east of "McVeighs" (3).

*Zosterophyllum australianum.*
cf. *Hedeia corymbosa.*
cf. *Hostimella* sp.

Quarry on Yarra Track, 10½ miles east of "McVeighs" (3).

*Zosterophyllum australianum.*

Road cutting on Warburton-Wood's Point-road, about 16½ miles east of Warburton and adjacent to Yankee Jim's Creek (3).

*Pachytheca* sp.
*Zosterophyllum australianum.*
*Hostimella* sp.
"*Pinnately branched axes*" cf. Mt. Pleasant, Alexandra (1).
"*Stems with small spirally arranged elevations or depressions*". cf. Mt. Pleasant (1).

Indeterminate plant fragments occur at several localities between McVeigh's and McMahon's Creek, 11½ miles east of Warburton.

LILYDALE DISTRICT.

Hull-road, Parish of Mooroolbark, 14 chains south of its junction with the main Melbourne-Lilydale-road. Gill's loc. 1 (2).

*Sporogonites Chapmani.*
*Yarravia* cf. *oblonga.*
*Zosterophyllum australianum.*
cf. *Hedeia corymbosa.*
cf. *Hostimella* sp.

Killara, Syme's Homestead (*vide* Gill, same volume).

cf. *Hedeia corymbosa.*

In adjacent quarries called Syme's Tunnel and Syme's Quarry indeterminate plant fragments occur.

WALHALLA DISTRICT.

Knott railway cutting below bridge (9).

*Hostimella* sp.

Thomson River—"Jordan River Beds" (11, loc. 1, 10).

*Baragwanathia longifolia.*
cf. *Hostimella* sp.

Walhalla—Centennial Beds.

Loc. 1, about half a mile up east branch of Stringer's Creek (9).
*Sporogonites Chapmani* f. minor.
Loc. 2, North-road Quarry, about 1 mile north of Walhalla on Walhalla-Aberfeldy-road (9).
*Hostimella* sp.
*Zosterophyllum australianum.*
*Sporogonites Chapmani.*
*Pachytheca* sp. (1).

Plant remains have been recorded also from Platina (8, 11, loc. 2), and by Thomas from Gould (4) and from cuttings on the Telbit-road (12).

South Gippsland.

Silurian inlier, Parish of Kongwak, occupying allotments 15A, 15, 16, 12c, indeterminate plant fragments have been recorded as *Haliserites dechenianus* (7, 8).

Rhyll, Philip Island, No. 1 Bore, 327-350 feet.

cf. *Thursophyton* (8).

Livingstone Creek, between Cape Liptrap and Waratah Bay (8).

cf. *Hostimella* sp.

"*Circinately coiled stem tip*". cf. Mt. Pleasant (1).

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[PROC. ROY. SOC. VICTORIA, 56 (N.S.), PT. II., 1945.]

# ART. VIII.—*Note on Cretaceous Strata in the Purari Valley, Papua.*

By S. WARREN CAREY, D.Sc.

(Published by permission of the Directors of the Australasian Petroleum Company.)

[Read 11th November, 1943; issued separately 30th June, 1945.]

The phragmacone of a belemnite was found in the upper Purari Valley in January, 1894, by Sir William MacGregor, (1). No further geological observations were made in that area until 1940 when Cretaceous strata were found by the present writer. It now appears that there are extensive outcrops of Mesozoic rocks in the area between Hathor Gorge and the Paw Valley, which lies some 15 miles east of the gorge on the left bank of the Purari. To date, only four field days have been spent on these exposures, so that our knowledge of the structure and succession is still rather rudimentary. The available data concerning these rocks are presented on a plan of the Paw Creek area (fig. 1).

Four straight sections have been measured, all within the same stratigraphic interval of about 6,000 feet. There is no direct evidence of fault repetition in this thickness, but some anomalous dips and disturbed strata have been noted and the examination has not been sufficiently thorough to deny the possibility of some faulting which might affect the observed thickness. However, a thickness of over 5,000 feet is found both in Sisa Creek and in the Paw Creek sections, and it is unlikely that detailed mapping would reduce the outcropping thickness of Lower Cretaceous strata to less than 5,000 feet, with the base still not exposed.

The sequence consists of massive or thick-bedded sandstones, and dark thin-bedded mudstones. The sandstones are dark-coloured and very hard, and in the field were thought to be tuffaceous, and described as greywackes. A typical sample (112) was examined in thin section, and found to consist almost entirely of materials of volcanic origin, not noticeably worn. The slide consists largely of plagioclase in subeuhedral forms. Quartz is present in angular grains, but it is quite subordinate to the plagioclase. Magnetite is common and apatite in small crystals is

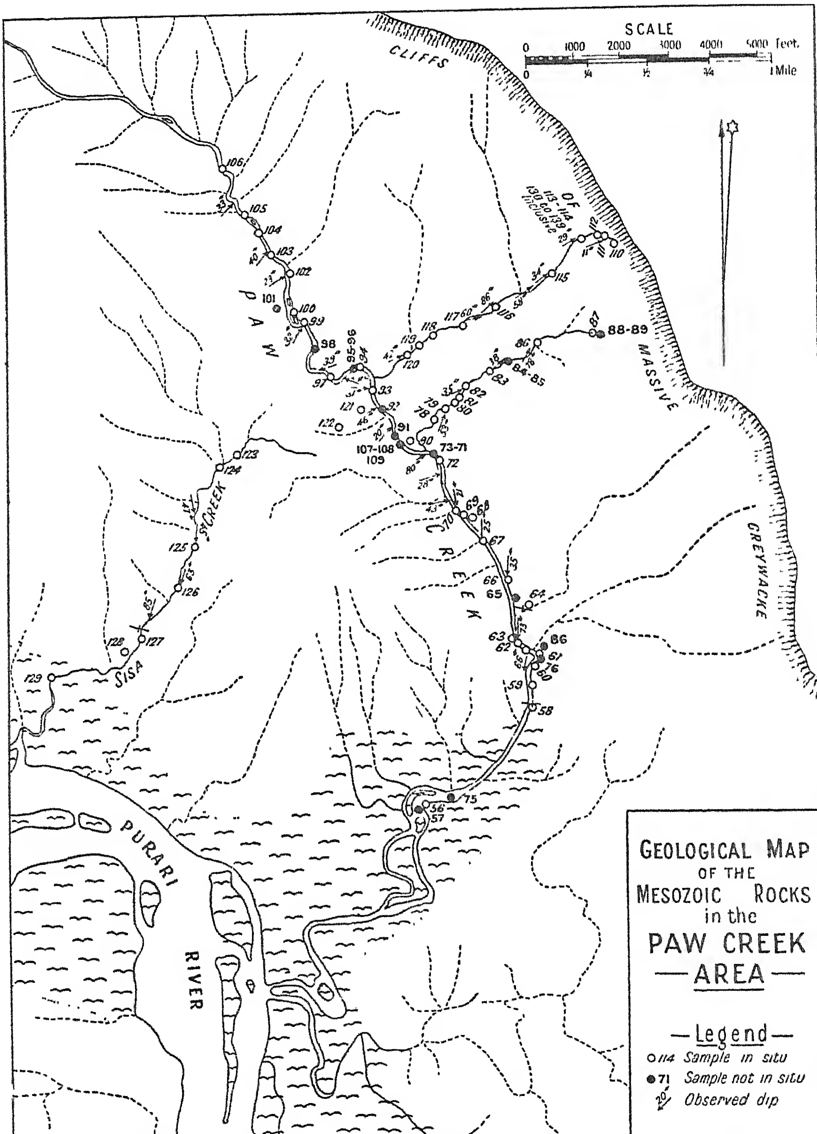


FIG. 1.—Paw Creek Area.
(Co-ordinates of south-west corner of map are 145° 56′ E., 6° 56′ S.)
"For the figure 86 on the lower portion of Paw Creek read 186."

present. There is a good deal of interstitial chlorite with epidote, but no real groundmass. Former ferro-magnesian minerals are represented mainly by their decomposition products, but a few ragged pieces of hornblende are present.

The sandstones are usually unfossiliferous, but one richly fossiliferous horizon was found packed with molluscan material. This horizon has been called the *Exogyra* bed. It is not more than 10 feet thick. Associated with it are thin bands of biscuity shales with indeterminate plant remains. The *Exogyra* bed has only been found along the north-east side of Paw Creek Valley about 1,000 feet from the top of the cliffs, which indirect evidence suggests may be capped with Eocene *Lacazina* limestone.

A meagre fauna of foraminifera and ostracoda and echinoid spines was found in the mudstones by Dr. Glaessner (2). He also reports that the *Exogyra* bed contains *Exogyra* cf. *couloni*, *Ostrea*, and a gastropod and a pelecypod not determinable on the samples available. Both assemblages are determined by him as of Aptian-Albian age.

Overlying the Cretaceous rocks are lower Tertiary strata which in different sections rest on different horizons of the Cretaceous beds. Thus on the north-east side of Paw Creek 3,700 feet of dominantly arenaceous strata with the *Exogyra* bed about 1,000 feet from the top, are present below the Eocene. On Sisa Creek only 2,600 feet of arenaceous beds are present beneath the *Lacazina* limestone, and the *Exogyra* bed is not present On the lower part of Paw Creek itself, only 1,100 feet of the arenaceous beds are present followed by limestone. Again the *Exogyra* bed is missing. In Noakes's Chimbu section (4) on the other hand, the stratigraphic equivalents of these Paw Creek beds, including the molluscan bed, are followed by a considerable development of Cenomanian strata, before the *Lacazina* limestone is reached. While some of these relationships are possibly complicated by faulting, it is difficult to escape the conclusion that a strong erosion interval amounting probably to angular unconformity separated the Cretaceous and Eocene in the Purari area. No angular unconformity has so far been observed in the field.

Paw Valley Samples not *in situ*:

The material collected not *in situ* in the Paw Valley, falls into six categories:

(1) Material definitely derived from the *Exogyra* bed (samples 84, 85, 88, 89).—These samples occur in a scree slope at the foot of a cliff in which the *Exogyra* bed is known to outcrop, and they are identical in lithology and fauna. They need no further comment.

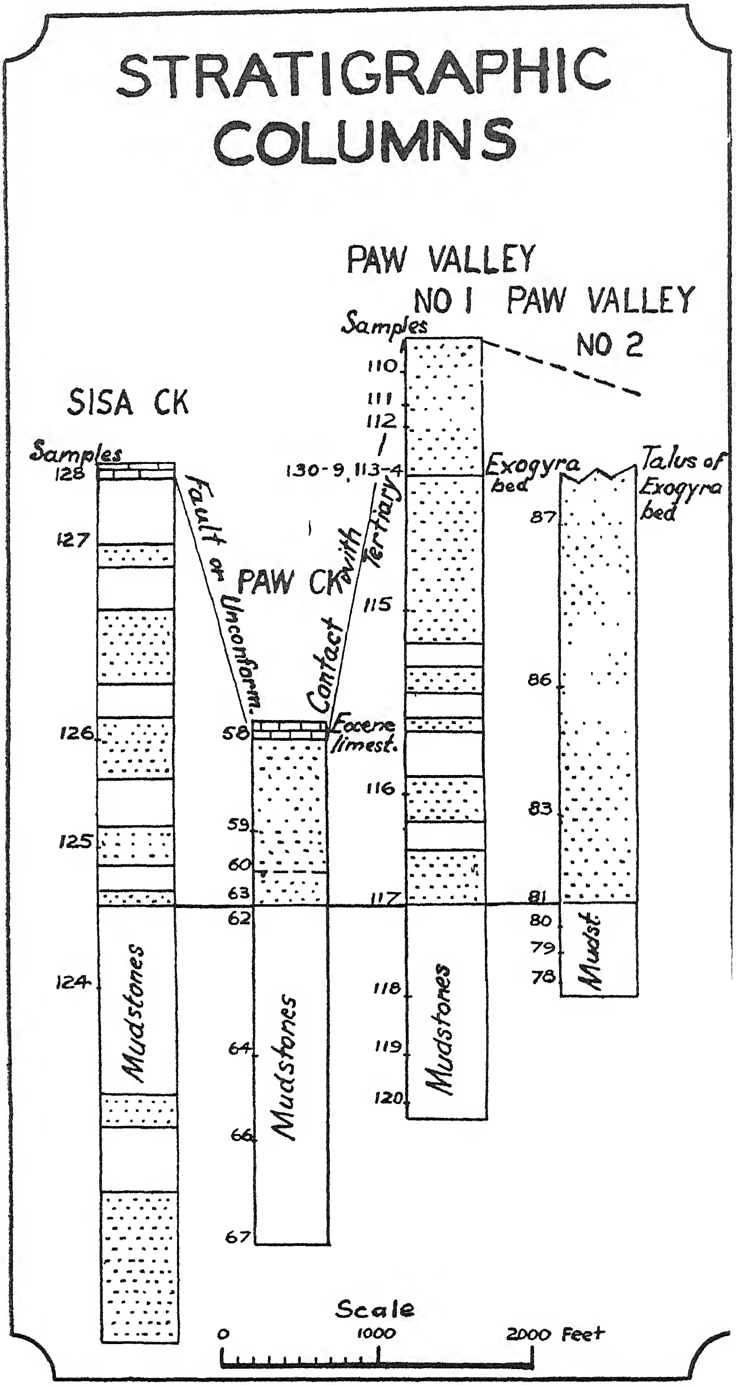


Fig. 2.—Paw Creek Area.

(2) Belemnite-bearing sandstone (sample 186).—A large belemnite was found in an otherwise barren sandstone block in the Paw Creek bed (for locality see map). It could not have travelled far for the belemnite was quite loosely attached to the sandstone. The belemnite was determined by Dr. Whitehouse as *Tetrabelus* n.sp. It is now described by Dr. Glaessner as *Tetrabelus macgregori* after the distinguished pioneer who half a century ago first recorded the presence of belemnites and Mesozoic strata in this part of New Guinea.

There is no reason to believe that the belemnite belongs to the *Exogyra* bed itself; it seems more probable that it was derived from one of the sandstones which are not generally fossiliferous. Near where the belemnite was found a molluscan sandstone was found (sample 61), carrying large numbers of an oval pelecypod referred by Glaessner to the genus *Pseudavicula.* This has a different lithology from the *Exogyra* bed, and the rest of the loose boulders, though the genus is present in other samples. Like No. 186, this sample is soft and little abraded and does not appear to have travelled far.

(3) Plant-bearing material (samples 75, 76).—A couple of well-worn pebbles of biscuity shale containing plant remains were found in the bed of Paw Creek. Their source is apparently somewhere among the strata in the Paw Valley, which as far as is known, are all Cretaceous, except perhaps a capping of Eocene limestone on top of the range overlooking it on the north-east. Plant-bearing beds of not very different lithology were found *in situ* in close association with the *Exogyra* bed, but the plant remains there were very broken with no recognizable pinnules. Samples 75 and 76 were sent to Dr. A. B. Walkom, who reported that they are "too fragmentary for very accurate determination. They represent portions of pinnae, usually with several elongated, somewhat wedge-shaped pinnules with venation of a general sphenopteroid type. Thus they belong to a species of the form-genus *Sphenopteris.* Of the species known to me (Walkom) as occurring in Australia, the Purari River specimens show some resemblance to *Sphenopteris erecta* (Tenison-Woods) which has been figured (Queensland Geological Survey, Publication 263, Plate 5, figs. 4 and 5) from the Burrum series of Queensland. The Burrum series is of Cretaceous age. . . ."

(4) *Lacazina* limestone (samples 56, 73, 74, 128).—Two specimens were collected from boulders of *Lacazina* limestone in the bed of Paw Creek about 4 miles from the mouth. They are both from fairly large though well-worn boulders, and occur in an area believed to be entirely Mesozoic. The only reasonable interpretation of their occurrence seems to be that the Eocene limestone must cap the range on the north-east side of the valley at least in some parts, and that the material has fallen and been

transported down the mountain side to the stream bed. If this interpretation is correct, the nearest possible point of origin is over a mile away, and 2,000 feet or more above.

(5) Cone-in-cone structure (sample 92).—In several places in the Paw Valley pieces of hard shaley rock were found showing well developed cone-in-cone structure. This has apparently been derived from the Cretaceous strata, but was not observed *in situ*.

(6) Molluscan calcareous sandstone (samples 57, 65, 75, 77, 91, 98, 101, 107, 108, 109, 140).—At several points on the floor of the valley both near the head and near the mouth a large number of well-worn blocks of hard calcareous sandstone packed with fossils was found. These have a different lithology from the *Exogyra* bed, which is softer and much less limy, and there is no definite reason to assume that they belong to the same horizon. However, no blocks of this material were found in either of the tributary creeks where the *Exogyra* bed is known to outcrop. It may be, however, that the *Exogyra* bed is a facies of the same bed as yielded the other samples, and that it is for this reason that the calcareous type was not found in the section or creeks containing the *Exogyra* bed. In any case, the horizon of the Molluscan material cannot be very different from that of the *Exogyra* bed. There is a fair amount of variation between the many blocks of this group. A fine-grained type is packed with small gastropods, and approaches in character towards a hard blue limestone. Other types have more pelecypods. Another type is quite pebbly. According to Glaessner, the pebbles consist of hard grey marl, red and dark cherts, quartz, &c., and some phosphatic nodules.

The following molluscs have been determined by Dr. Glaessner from these samples.—*Trigonia, Cardium, Ptychomya, Pseudavicula, Ostrea, Mytilus, Alaria, Nerinea*, and *Tetrabelus macgregori*. Several other genera are present, but not sufficiently well preserved to be determined.

These molluscan beds are of considerable interest because the rock is hard and water-worn boulders of it have a characteristic conspicuous lithology which draws the attention even of the non-geologist passing it in the stream, with the result that it has been found over a large tract of country. If the doubtful cases are included it extends from near Kerema across the middle Purari to the Waghi Valley, and westwards as far as the Strickland.

(*a*) Numerous samples (15–26 inclusive, and 33) of these molluscan beds were collected by the writer in the bed of Wabo Creek. The lithology is identical with the Paw Creek material. Here it is associated with numerous large blocks of silicified wood, some of them a foot or so in diameter (sample 26F). The

molluscan beds were not found *in situ* for the section examined by the writer there did not reach them, but it was clear from structural relationships that the molluscan material must be derived from an horizon not very far below the Eocene limestone.

(*b*) Several samples were found in the Wheian Valley by the writer in 1939 (samples 69A–69F). Here again the structure is such that it is apparent that the molluscan beds cannot be very far below the lowest Tertiary beds. At the base of a section measured between the Wheian and Pio rivers, oyster bearing beds were found *in situ,* though not well preserved. These are about 400 feet below the base of the Tertiary strata. In this case it was only after comparison with samples from Paw Creek that the Cretaceous age could be inferred.

(*c*) Sample 144 collected in Hathor Gorge by the writer, and a sample collected by Patrol Officer Ethell a few miles south-west of Lake Tebera, also have this characteristic lithology.

(*d*) Further afield it is interesting to note that E. R. Stanley's description (3) of "dark calcareous sandstones and bluish-grey limestones containing *Orbitolites, Gryphaea, Modiola, Aviculopecten,* and *Belemnites*" at the "head of Karova Creek", fits very well with the lithology and facies of these other Cretaceous rocks, though subsequent work has thrown doubt on the authenticity of Stanley's locality.

(*e*) Dr. Glaessner states that a pebble of bluish-green sandstone containing abundant molluscan shells was collected by G. Barrow on the Strickland River. This pebble resembles the molluscan beds in Paw Creek. Glaessner also correlates these molluscan beds with the top of Noakes' "stage 2" in the Chimbu Valley section (4). Furthermore a fossiliferous rock corresponding closely to the Paw Creek molluscan beds was found by Mr. Vial, Patrol Officer, about 3 miles east of Mingenda.

Thus, these molluscan beds are likely to prove of great value in the correlation of the Cretaceous strata throughout a wide province. Evidence suggests that the richly fossiliferous material is confined to a narrow zone near the top of a thick section of sparsely fossiliferous sandstones and shales. Being resistant to erosion by virtue of its extra lime content, and the fossils being very conspicuous on waterworn surfaces, boulders derived from this narrow zone have been found and recorded over a wide area.

THE PURARI FORMATION:

A. Gibb Maitland has referred to the belemnite bearing strata recorded by Sir William MacGregor as the Purari beds (5). So far as the writer is aware the term "Purari beds," or "Purari formation" has not been used in any other sense in any published record. Hence it is proposed that this term be adopted.

The Purari formation as now defined is a sequence of marine mudstones and sandstones, with a thin zone near the top rich in lamellibranchs, gastropods, and occasional belemnites, which outcrops in the middle and upper Purari Valley. Its fauna is described by Glaessner, and determined by him as belonging to the upper part of the Lower Cretaceous. Its thickness has been proved to exceed 5,000 feet, but neither the base nor the top is as yet precisely determined. Fragmentary data suggest that the formation may be identifiable over a region embracing the upper Strickland Valley, Chimbu, the upper and middle Purari Valley, and possibly the hinterland of Kerema. The molluscan zone is a characteristic marker of this formation.

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[PROC. ROY. SOC VICTORIA, 56 (N S.), PT. II., 1945.]

# ART. IX.—*The Mesozoic Stratigraphy of the Fly River Headwaters, Papua.*

By N. OSBORNE.

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## Abstract.

The headwaters of the Fly River, known to the local natives as Wok Feneng, expose a thick section of Mesozoic sediments in a south dipping monocline on the rugged southern fall of the Central Highlands of New Guinea. These underlie, without apparent angular discordance, the Tertiary limestones supporting the rough mountain ranges or "Limestone Barrier" along the foot of the Central Highlands in western Papua.

The Mesozoic section totalling nearly 7,500 feet of marine sediments is divided on lithological grounds into two distinct units of sedimentation, each dominantly argillaceous at the top and arenaceous at the bottom. These two units have been named Feing and Kuabgen groups respectively. Both are fossiliferous and an examination of the fossils by Dr. M F. Glaessner establishes the age of the Feing group as Cretaceous (Cenomanian-Albian) and of the Kuabgen group as Upper Jurassic.

The character of the basal Kuabgen rocks suggests a derivation from granitic basement which probably underlies them at no great depth The time break between the Kuabgen and Feing groups, together with the composition of the basal Feing deposits suggests an Albian transgression over the uppermost Jurassic. An important unconformity is indicated also between the Feing group and the Tertiary limestones by another big time break and a sudden and complete change in lithology.

## Introduction.

The object of this paper is to describe the occcurrence of Mesozoic sediments in the headwaters area of the Fly River, referred to hereafter as the Feneng area, to give an account of the section exposed and to indicate its significance in respect to the Mesozoic geological history of New Guinea.

The Fly River rises in the Central Highlands of New Guinea in Papuan territory about 40 miles from the boundary with Netherlands New Guinea and very close to the Mandated Territory border. The main headwaters stream is called by the local natives, Wok Feneng, Wok being the native word for water. The principal tributaries of the Fly are the Alice River (Ok Tedi) to the west and the Palmer and Strickland Rivers to the east.

In this area a series of extremely rough precipitous limestone mountains rises along the foot of the Central Highlands, to be breached in deep narrow gorges by the Fly River and many of its larger tributaries. This "Limestone Barrier" has presented a formidable obstacle to exploration of the main divide.

Karius and Champion (1929) were the first to negotiate these limestones when they crossed the Central Highlands from the Fly to the Sepik River in 1927-8 but they made no observations of stratigraphic value.

Earlier explorations failed to penetrate the Limestone Barrier, but samples collected from the upper Alice River by Austin (1923) and examined by Chapman (1925), and from the Wai Mungi (1924-5), indicated the limestones to be of Tertiary age; while Everill in 1884 found in the Strickland River or one of its tributaries at a point which has since eluded identification, fossils recognized by Wilkinson (1888) to be Cretaceous. | Further study by Dr. Glaessner and writer of Everill's record and comparison of his map with the recently compiled air photographic maps of Island Exploration Coy. indicate that the farthest point reached by his expedition was in the main Strickland River some 3-4 miles below the junction with the Murray River. The locality referred to by Wilkinson as the source of the Cretaceous fossils he identified, is now recognized as one in which very fossiliferous late Tertiary rocks outcrop, indicating that the Cretaceous specimens were not found in situ. |

Downstream from the outcropping limestones Everill also found waterworn pebbles containing ammonites determined by Etheridge (1890) to be Jurassic in age. Probably based on this discovery, Stanley (1923) and later David (1932) show on their maps a patch of Jurassic on this river around latitude 6-7° south. Field investigations by geologists attached to Island Exploration Company 1938-9 have shown that no Mesozoic rocks outcrop south of the Limestone Barrier and that the pebbles found by Everill must have been brought down by the swiftly flowing waters from some locality considerably further upstream. Likewise incorrect are the Mesozoic outcrops shown to occur on the Palmer River below its confluence with the Tully River, extending across to the Fly, and based apparently on stream pebbles picked up by Sir William McGregor and determined by Gregory and Trench (1916).

In 1937 a gold prospecting expedition headed by Ward Williams investigated some of the Fly, Strickland, and Sepik headwaters, and in the upper Om River one of the headstreams of the Strickland, they discovered "black shales studded with magnificent ammonites."—Campbell (1938). Specimens of these ammonites handed to Dr. W. Chawner of Island Exploration Coy. were sent to Dr. Reeside of the U.S. Geological Survey who reported (personal communication) that they are Perisphinctids, indicative of an upper Jurassic or lower Cretaceous age. W. Korn, J. Burke, and W. Kienzle, members of the expedition travelled overland to the Central Highlands by way of the Fly River route and the Wok Kup but have not made available any maps or notes of their journey.

Geologists of Island Exploration Coy. investigating the petroleum possibilities of the Fly River region also found the limestone mountains a serious obstacle to the exploration required to complete the stratigraphic section. Air reconnaissance had shown that the limestone belt was succeeded to the north by an entirely different terrain and that in the main Fly River headwaters (Wok Feneng) and Strickland valley at least, south dipping monoclinal conditions of considerable extent gave promise that good sections of the pre-limestone strata might be exposed there.

Since transport in this remote and mountainous country was confined to native carriers, the difficulty in keeping geological parties beyond the Limestone Barrier supplied sufficiently to remain out long enough to perform useful work was one that could be solved only by the introduction of air transport. Consequently it was decided to send specially equipped expeditions into the upper reaches of both the Fly and Strickland Rivers, and to supply them with foodstuffs by dropping from the air at their most forward bases It was decided also to send an expedition into the Upper Palmer River although the geology appeared from the air to be complicated by faulting. Here, however, the Limestone Barrrier is not so strongly developed and it is possible to employ native canoes for transport much closer to the area to be examined, thus obviating the necessity for air transport the success of which depends on clear weather, a condition not frequently fulfilled in this country. The months of December and January were chosen as the period of the year most likely to provide good weather.

The upper Palmer expedition was made in October-November, 1938, under the leadership of Dr. W. Chawner with W. D. Mott as assistant geologist. They measured and described some 3,450 feet of section which they considered unconformably underlies the Tertiary limestone, the upper part of the section being predominantly argillaceous, the lower arenaceous. The contained fossils were examined by Dr. M F. Glaessner, company palaeontologist, who regarded them as indicating a Cretaceous (Cenomanian-Albian) age.

The Strickland expedition under G. Barrow, December, 1938, and January, 1939, ascended that river with great difficulty to a point some 16 miles above Murray Junction without getting out of Tertiary strata and was prevented by supply troubles from penetrating further.

## The Wok Feneng Expedition.

The upper Fly expedition, known as the Wok Feneng Expedition, led by the author with the late G. Sadler, assistant geologist, E. Ross and R. Ely, field assistants, and 70 Papuan natives,

started November 27th, 1938, from a base on the Palmer River, 12 miles above its junction with the Fly River and the limit of water transport convenient to the expedition. The author had made an air reconnaissance with Dr. Washington Gray a few days previously with the object principally of selecting a suitable locality for establishing a base beyond the Limestone Barrier for dropping supplies.

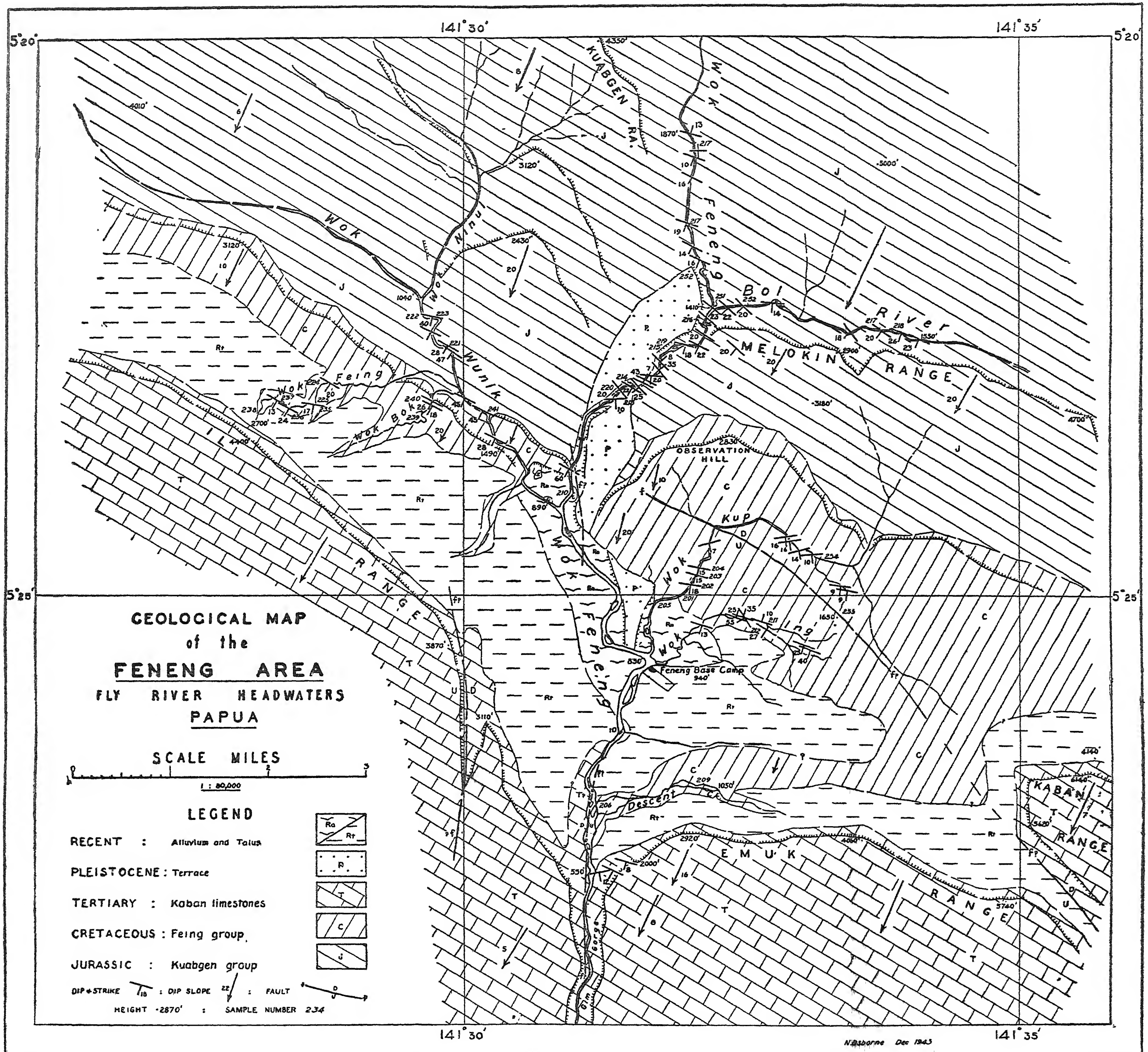
There is no native track across the limestones here and the route followed was roughly that taken by Korn, Burke, and Kienzle along the lip of the Fly River gorge on the east side.

The selected dropping base on the Wok Feneng at its junction with the Wok Kup and Wok Ing was reached December 16th, the journey of 30 miles taking 20 days, adequate testimony to the difficult nature of the country which makes it necessary to relay supplies and equipment in short stages. Base camp was established here and all labour set to work immediately to cut a clearing in the jungle for dropping supplies. This was the Feneng Base Camp.

On arrival the party had enough food to allow the supply aeroplane seven days' grace on its scheduled date of arrival—December 22nd—and then in case of failure, enough to make a five days' return to the forward base on the south side of the Limestone Barrier. Fortunately the weather was fine December 23rd and 24th, and enough food was dropped and recovered to give the party a total of six weeks in the Feneng area.

Except for a small scale air sketch map by Campbell (*ibid.*) and the journey of Korn, Burke, and Kienzle, about which there was no record, the Feneng area was previously quite unexplored and unmapped. The party therefore had to make its own topographic as well as geological survey. It had been intended originally to fix the position of the Feneng Base Camp by astronomic observation using a theodolite and wireless time. However the portable radio set went out of commission before reaching the Feneng area so instead, careful bearings were taken to prominent peaks on the Il and Emuk Ranges, which were likely to be visible both from the Feneng area and from the south side at points whose positions were known accurately. With these and a latitude determination, the Feneng Base was fixed with reasonable accuracy. A base line was laid down in the clearing and from it a triangulation net was made of all other outstanding features visible. Individual traverses were then made by pace and compass methods using aneroid and hand level for heights.

A few traverses were made by Sadler and the author working together, but most of the exploration was carried out by each geologist working separately with his own carrying line in expeditions lasting up to eight days away from base.


GEOLOGICAL MAP
of the
FENENG AREA
FLY RIVER HEADWATERS
PAPUA
SCALE MILES
1 : 80,000
LEGEND
RECENT : Alluvium and Talus
PLEISTOCENE : Terrace
TERTIARY : Kaban limestones
CRETACEOUS : Feing group
JURASSIC : Kuabgen group
DIP + STRIKE : DIP SLOPE : FAULT
HEIGHT ·2870' : SAMPLE NUMBER 234
141°30'
141°35'
5°20'
5°25'
KUABGEN RA.
Wok Feneng
Wok Ninul
Wok Wunik
Bol River
MELOKIN RANGE
OBSERVATION HILL
Wok Kup
Wok Feing
Wok Bok
ILI RANGE
Feneng Base Camp
Descent Ck
EMUK RANGE
KABAN RANGE
N. Osborne Dec 1943

The party left the Feneng area January 27th, arriving back at the forward base on the south side of the Limestone Barrier January 30th, 1939.

ACKNOWLEDGMENTS.

The author wishes to thank the Directors of Island Exploration Company Pty. Ltd. and Dr. K. Washington Gray, Chief Geologist, for permission to present this paper; Dr. M. F. Glaessner for his palaeontological determinations and helpful discussion; the Company staff at Kiunga Base Camp and the crew of Guinea Airways seaplane for their co-operation, and especially the late G. Sadler, E. Ross, R. Ely, and the Papuan natives who made up a most efficient and willing field party under very difficult and often hazardous conditions.

## Physiography.

The area covered by this paper is that part of the southern slopes of the Central Highlands of New Guinea occupied by the headwaters of the Fly River. It is a region of sharp relief and mostly high elevation.

The Limestone Barrier rearing conspicuously along the foot of the Central Highlands in this area is divided into three sections, called from west to east, Il, Emuk, and Kaban Ranges. The Il and Emuk Ranges are separated by the Gim Gorge (Pl. V., figs 1 and 3) through which the Fly River leaves the mountains to commence its 590 miles run to the sea. The Gorge is a narrow cleft less than 2,000 feet wide at the top and 1,500 feet deep, diminishing practically to river level down dip some 6½ miles downstream. A conspicuous though narrow air gap separates the Emuk from the Kaban Range. The three ranges present almost vertical cliffs, 1,500-2,000 feet high towards the north, but slope gently to the south. The highest point noted on the Il Range is about 4,400 feet, on the Emuk 5,700 feet, and on the Kaban Mt. Sari is about 7,000 feet.

The soft shales and sandstones immediately underlying the thick limestones have been much less resistant to erosion, and now constitute a wide stretch of low and subdued country at the base of the great limestone scarps, protected and modified by enormous talus slopes and residual blocks left by the receding scarps. The talus slopes and residual cover themselves have been modified by the tendency of the underlying shales to slump, the result being that they have assumed a low slope and possess a roughly mammilated surface at a distance from the scarps.

Below these soft strata the rocks are harder again, and becoming predominantly sandstones and conglomerates support high country in which has developed a series of conspicuous strike

ridges and dip slopes, the Melokin and Kuabgen being perhaps the most prominent (Pl. V., fig. 2). These constitute the southern limit of the Central Highlands proper. They are generally lowest where the Wok Feneng cuts through them in a gorge only a little less formidable than the Gim Gorge, and rise east and west outwards toward the divides with the Palmer and Alice Rivers respectively, where the relation of topography to geology becomes obscure. The Hindenburg Range comprising the core of the Central Highlands in this area is nowhere less than 8,500 feet high, some peaks reaching 10,500 feet. The Kuabgen Range rises to a height exceeding 4,400 feet, while the most prominent point on the Melokin Range is 4,700 feet. Further south, Observation Hill on a well developed strike ridge is 2,830 feet, and on its counterpart west of the Wok Feneng a peak 3,100 feet high was observed.

The Feneng is undoubtedly the main stream, but the Bol and the Wunik are only a little less important as water carriers All the large streams are rapid and turbulent, have steep-walled valleys and are more or less choked with great boulders. Near the Feneng Base Camp the Feneng is relatively quiet for a distance of about 2 miles upstream, the width is 200-300 feet, and although shallow a canoe can be used with difficulty; but downstream the gradient to the mouth of the Gim Gorge averages over 90 feet per mile in a series of cascades, the width reducing to 150-200 feet. Between the junctions with the Wunik and the Bol the gradient increases from 60 to 110 feet per mile, width varying from 60 to 150 feet. Above Bol junction in the 2½ miles traversed the river is a torrent falling at the rate of over 300 feet per mile and the stream is full of enormous boulders which almost bridge it in places.

A high terrace sloping downstream along the Feneng from just above Bol Junction where it is about 300 feet above present river level to near Base Camp where it falls to less than 50 feet indicates an earlier course of the stream. A series of soft horizontal thin bedded clays in the low country around the confluence of the Feneng and its tributaries Kup and Ing and south of Base Camp suggests the existence of quite a considerable lake in perhaps the not very distant past, formed probably through a great landslide damming the mouth of Gim Gorge.

Despite the precipitous and sometimes almost vertical slopes, the whole country is clothed in dense jungle with the exception only of the small and relatively few native gardens, and a scrubby but tough vegetation on the top of sandstone ridges. Numerous conspicuous bare rock scars on the cliffs of the limestone ranges indicate the prevalence of large rock falls. Somewhat less conspicuous but still numerous are similar scars on the cliffs of the sandstone ridges.

The rocks are usually well exposed in the streams, but these are not always completely accessible and much physical effort is required to climb in and out of gorges to study exposures.

The shale members have suffered considerable slumping so that these rocks are frequently obscured. Particularly is this the case with the thick Feing mudstones in the main Feneng. Smaller streams, tributaries of the Wunik, provided the best sections in these strata.

## Stratigraphy.

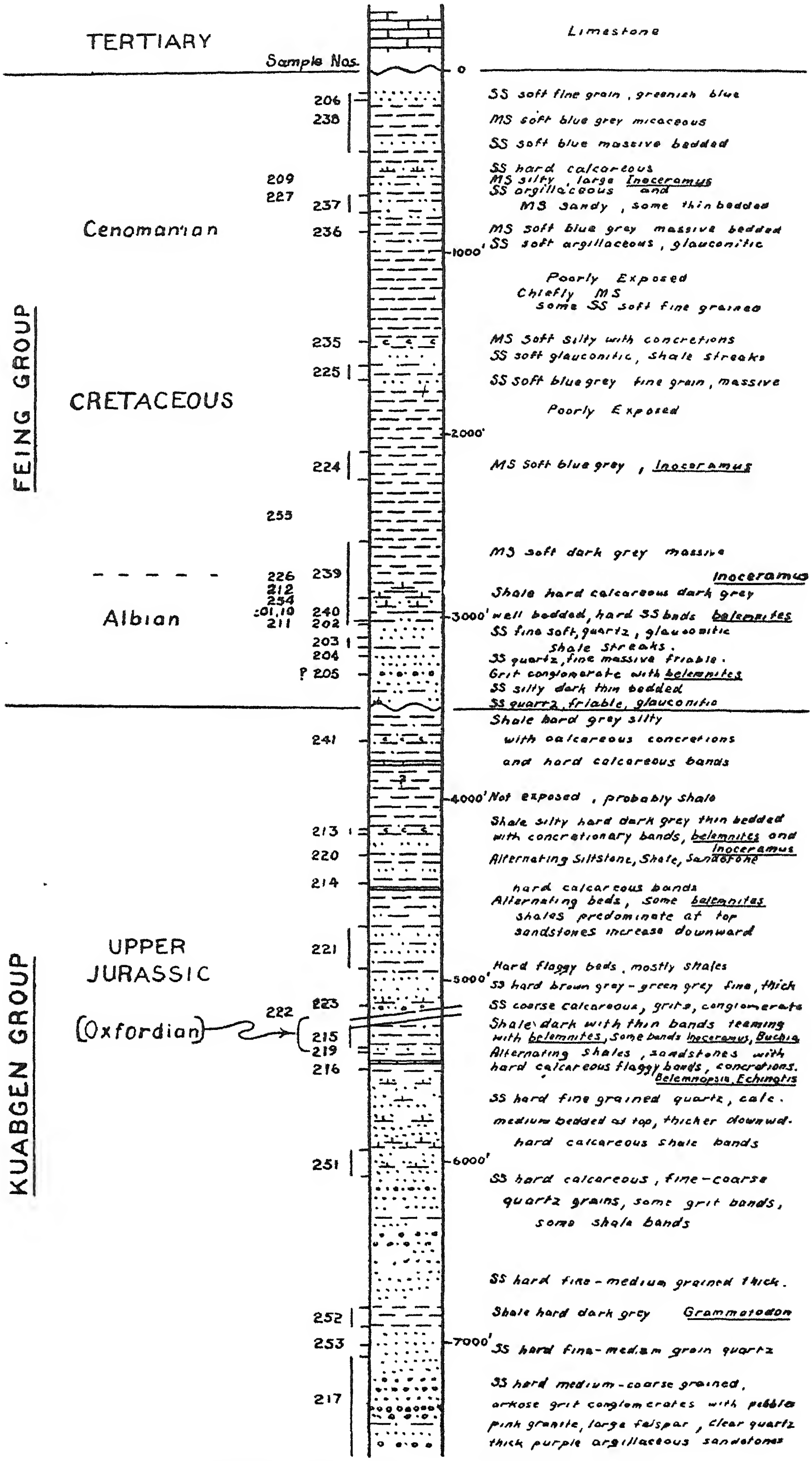
A thick section of marine sedimentary rocks totalling nearly 7,500 feet was found underlying the Tertiary limestones in the Feneng area. This section has been divided on lithological grounds into two distinct units of sedimentation named respectively Feing group and Kuabgen group. Both are dominantly argillaceous at the top and pass downwards into dominantly arenaceous strata, but the rocks of the lower Kuabgen group are slightly indurated and have a definitely older appearance.

Although the section is not very fossiliferous as a whole, *Inoceramus* and belemnites are fairly abundant in several widely scattered zones. Thus the age was recognized in the field as generally Mesozoic. Glaessner has examined the macro- and micro-fossils contained in the collected specimens and has assigned more specific age within the Cretaceous and Jurassic to the two lithological units. His determinations and conclusions are recorded in a paper entitled "Mesozoic Fossils from the Central Highlands of New Guinea," published simultaneously in these Proceedings.

The rock sample localities are shown on the accompanying geological map, and their position in the stratigraphic sequence on the columnar section for the Feneng area (fig. 1). This section illustrates the general character and thicknesses of the Cretaceous and Upper Jurassic sediments.

The contact between the Tertiary limestones and the Feing group has not been seen anywhere owing to the universal cover of talus at the foot of the great cliffs which mark the outcrop of these limestones everywhere in the Feneng area. However there is an abrupt and complete change in lithology and a big time break between them, the uppermost Cretaceous and the whole of the Eocene apparently being missing.

Chawner has reported the same situation in the Upper Palmer River some 20 miles east south-east, his Luap and Narin formations, sandstone and mudstone respectively, being almost identical in lithology, fauna and total thickness with the Feing group, while the Tertiary limestones from the two areas are also similar in character.




COLUMNAR SECTION for the FENENG AREA

Fig. 1.

However whereas Chawner postulates an angular unconformity between the Narin formation and the Kaban limestones, no evidence of an angular break was seen in the Feneng area. No actual contact was seen in the Palmer area either and the situation there was obscured also by faulting. In both areas the limestones appear to be underlain by the same Cretaceous formation, the close agreement in thickness and character between the Cretaceous sections exposed in the upper Palmer and the Feneng area suggesting that no persistent unconformity is present. Furthermore, wherever observed in the Feneng area the Feing mudstones appear to be dipping at about the same angle as the overlying limestones.

The evidence in the Feneng area suggests rather that the break between the Feing group and the Tertiary limestones represents chiefly a long period of non-deposition without appreciable folding or erosion.

## Feing Group.

Extending from the foot of the great north-facing scarps of the Il, Emuk, and Kaban Ranges to the lower slopes of the Central Highlands is a wide valley-like area whose subdued topography is in marked contrast with the high and rugged character of the remainder of the Feneng area. A covering of limestone talus and residual blocks occupies most of the surface, but many of the deeper streams have cut through it to expose a thick section of sediments, chiefly mudstones, dipping relatively gently toward the south. This subdued terrain is terminated northward by a prominent though not especially high standstone ridge which dips south beneath the mudstones.

Examination has shown that the mudstones grade downwards into the sandstones, the whole forming a sedimentary unit to which the name Feing group has been given—the Wok Feing being the stream in which the best section of the upper part was observed.

The whole series was not seen in one continuous section, but different parts of it are well exposed in the Wok Feing, Bok, Feneng, Kup and Ing, also in Descent Creek. From these it has been possible to work up a composite section. The total thickness so measured amounts to 3,400 feet minimum, part of the 200-250 feet of beds obscured by talus at the foot of the limestone cliffs no doubt belonging in the Feing group. This thickness is only an approximation, for outcrops showing dip are rare in the upper part owing to the prevailing massive character of the rocks, while their tendency to slipping and slumping on a large scale make even the best observations of dips a little uncertain.

The upper 2,800 feet, well exposed in the Wok Feng and the Wok Bok, are predominantly argillaceous consisting mainly of soft massive grey to blue-grey mudstones and silty micaceous mudstones, but with some thick zones of soft greenish-blue fine-grained sandy mudstones and argillaceous sandstones especially near the top. The sandstones are sometimes thick-bedded, sometimes thin-bedded, and often contain glauconite. Cone-in-cone limestone also is found on several horizons.

Towards the bottom the mudstones become darker, harder and more silty to consist largely of hard dark-grey to black silty shales, generally micaceous and frequently pyritic, medium to massive bedded and exhibiting spheroidal weathering with a yellow-brown ferruginous incrustation and giving off a strong sulphurous odour. Some of the beds are very calcareous, extremely hard and brittle.

Thin sandstone bands appear in these hard shales, becoming more important downward, and the section grades into argillaceous sandstones through a transition zone perhaps 100 feet thick.

The basal, dominantly sandstone, part of the group measures some 500 feet in the Wok Kup. No direct measurement was made in the Wok Bok because that stream plunges over a high waterfall in these rocks and is inaccessible, but from the elevation and dip the thickness would appear to be of the same order.

The sandstones are argillaceous at the top but less so downwards. The sand grains consist almost entirely of sub-angular to slightly rounded clear quartz, generally of fairly uniform size in individual beds. Glauconite is a common constituent throughout, distribution varying from even dispersion to scattered aggregation in pockets; occasionally it is so abundant as to give the rock a dark-green colour, often it is entirely absent. Thin beds of grey silty shale occur, particularly in the upper half of the sandstones. At some horizons thin grey shale streaks are conspicuous.

Bedding is generally medium to thick and mostly well defined. The strata are often fairly hard, especially at the top, with some very hard siliceous bands, but many of them are quite uncemented although tightly compacted and fall to pieces on being struck. There are also important zones of soft friable white sandstone consisting almost entirely of pure clear quartz especially towards the bottom.

Grain size is chiefly fine to medium becoming generally coarser downwards where there are some grits. Slightly waterworn pebbles of hard calcareous gritty conglomerate found in the Wok Kup downstream from the outcropping sandstones contain, in addition to abundant quartz and numerous belemnites, rounded

pebbles of hard calcareous shale and dark siliceous rock undoubtedly derived from the underlying Kuabgen group. These were not seen in place anywhere but it is believed they almost certainly come from somewhere in the basal Feing sandstones. A hard waterworn concretionary pebble containing canaliculate belemnites found among the stream pebbles at the same place is thought also to have been derived from the Kuabgen group by way of these conglomerates.

The Feing group generally is not visibly very fossiliferous In the upper argillaceous part thin bands rich in large *Inoceramus* sp. were found in Descent Creek from a position high in the section, in the Wok Feing low in the section, and in the Woks Kup and Ing about the bottom. The mudstones contain also a fairly rich assemblage of foraminifera, which Glaessner (see p. 165) regards as establishing a Cenomanian age for the upper part of the Feing group.

In the Wok Feneng just above its junction with the Wok Wunik the belemnite *Parahibolites blanfordi* occurs fairly commonly in hard dark shales of the transition zone. Similar belemnites also were seen on about the same horizon in the Wok Ing. Foraminifera from this zone are regarded by Glaessner as indicating an Albian age.

No recognizable fossils at all were recovered from the basal sandstone formation, *in situ*, but weathered fragments of belemnites up to nearly an inch in diameter were found in the Wok Kup downstream from the outcropping sandstones. They occur among stream pebbles which included the belemnite bearing conglomerate mentioned above, some of the included belemnites being apparently the same as those found loose. Sandstone boulders with similar belemnites were observed in the Wok Ing adjacent to outcrops of lithologically similar rocks underlying the transition zone, but here again the fossiliferous deposits were not seen in place. Cylindrical holes resembling in shape and size the belemnites occurring loose in the Wok Kup, sometimes empty sometimes filled with hard clay, were observed in thin bands in the sandstones exposed in the Wok Kup fairly low in the section, and in the Woks Bok and Ing near the top. Possibly these cavities once contained belemnites, although these fossils generally seem to be more resistant than the containing strata.

In any case, as indicated previously, the belemnite bearing conglomerate is considered to have come from the basal sandstones of the Feing group. Unfortunately, while the belemnites in the conglomerates are well preserved, it has been impossible to extract them from the rock so that their features can be examined. For this reason Glaessner is unable to determine them, although he states that they have a Cretaceous rather than Jurassic aspect. Since the basal sandstones form a continuous series of strata with the transition zone which has been established as Albian, it is probable that they, too, are of that age, or very little older.

Thus the Feing group is referred to the middle Cretaceous, Cenomanian-Albian. The palaeontological sub-division of this group into Cenomanian and Albian agrees very closely with the lithological sub-division into an upper, dominantly mudstone, and a lower, dominantly sandstone, formation, except that the lithological basis would include in the upper part the hard dark shales at the top of the transition zone which however contain Albian fossils.

In thickness, fossils and general character, the Feing group is almost identical with the combined Narin and Luap formations described by Chawner from the upper Palmer River, the only difference being that the basal sandstones in the Palmer appear to be thicker though the bottom of the section was not reached, and that the transition zone appears to be thicker too, thus:—

| FENENG AREA. | Feet. | UPPER PALMER. | Feet. |
|---|---|---|---|
| *Feing group:* | | *Narin formation:* | |
| Upper, chiefly mudstone .. | 2,800 | Chiefly mudstone .. | 2,125 |
| Transition zone .. .. | 100 | *Luap formation:* | |
| Lower, chiefly sandstone .. | 500 | Transition zone .. | 500 |
| | | Sandstone .. .. | 825 |
| | 3,400 | | 3,450 |

No contact between the Feing group and the underlying Kuabgen group was seen. However the Kuabgen group generally looks distinctly more indurated than the Feing, while the palaeontological evidence shows that there is a considerable time interval between the two groups, the uppermost Jurassic and much of the lower Cretaceous being absent. These points, together with the sharp lithological change from shales at the top of the Kuabgen to sandstones at the base of the Feing, with glauconite and gritty conglomerates containing weathered pebbles of the underlying Kuabgen group, suggest an erosional unconformity of some dimensions. In the Wok Wunik the Kuabgen shales are dipping at a higher angle than the overlying Feing beds where dips could be read; but as there is a gap of about 1,000 feet in which there are no outcrops and a still greater interval between exposures on which dips can be measured, while there is evidence in both units of increase in dip towards a maximum in the vicinity of the group boundary, this cannot be regarded as demonstrating an angular discordance. The general monoclinal conditions observed in the Feneng area give the impression that an angular divergence of no more than a few degrees at most can be expected.

## KUABGEN GROUP.

The strata belonging to this group occupy the increasingly higher and more rugged country on the south flank of the Central Highlands. They support a number of high strike ridges, prominent among which are the Melokin and Kuabgen Ranges, the latter giving the group its name.

The upper part of the group is rather poorly exposed in the area visited and the section has been made up as a composite from outcrops inspected in the Woks Feneng and Wunik. The lower and greater part of the group however is exposed practically as one continuous outcrop in the Wok Feneng and the Bol River, which here flow through gorges not uniformly so high but almost as difficult of access as the Gim Gorge.

The highest beds seen lie about 100 feet below the top of the group and consist of hard grey silty micaceous shales with calcareous concretions, massive bedded at the top but becoming thinner bedded downwards with some very hard calcareous bands intercalated These total about 250 feet in thickness and are followed by a gap of similar dimensions in which no outcrops were seen. Judging by the topography it is believed that this gap and also that at the top represent mainly argillaceous sediments. The next outcrops seen were hard dark-grey thin-bedded indurated-looking silty micaceous shales with hard concretionary bands and containing belemnites and *Inoceramus*. Below these are about 600-800 feet of beds, sometimes dominantly sandy, sometimes dominantly shaly, grey to greenish-brown in colour, thin to thick bedded, generally hard and often flaggy with frequent harder very calcareous bands; sometimes alternating hard sandstones, argillaceous sandstones and silty shales with some pyrite nodules. The shales often look indurated but the sandstones, though usually very hard, show no sign of alteration.

The sandstones increase in importance as the section is descended, becoming thicker and more numerous until there are some 250 feet consisting almost entirely of hard brownish-grey to greenish-brown fine grained sandstone, medium to thick bedded, with a thick hàrd calcareous coarse clear quartz sandstone including gritty bands containing some thick-shelled pelecypods, near the bottom.

At this stage the sequence is interrupted by structural complications in both the Wok Feneng and Wok Wunik, possibly 100-200 feet higher in the Feneng than the Wunik. In the Wok Feneng the monoclinal conditions are disturbed by two small anticlinal folds with associated faulting indicated by irregular dips and strikes, slickensides, breccias, calcite veins, and visible small faults. Similar manifestations of faulting are evident also in the Wok Wunik where, however, the traverse was not continued far enough to detect whether it is connected with folding.

No direct evidence was found to show the magnitude and nature of the faulting, but there is reason to believe that section is cut out rather than repeated, because a highly fossiliferous shale of peculiar appearance which occurs on the north side of the fault was not seen anywhere on the south side. Thus it is concluded, not very surely, that downthrow is to the south. However, the fossiliferous shale on the upthrow side is underlain by alternating

beds rather similar to those already described, suggesting that the same unstable conditions existed throughout the deposition of the strata now found on both sides of the fault, and therefore that the fault may be of relatively small dimensions.

The total thickness estimated for the upper part of the Kuabgen group is 1,710 feet with a thick coarse sandstone containing grit bands near the bottom. A conglomerate consisting of hard grey shale and sandstone pebbles in a fine sandy matrix observed in the fault zone in the Wok Wunik probably belongs here. Pebbles in this conglomerate resemble some of the hard calcareous shales and sandstones underlying the peculiar fossiliferous shales just mentioned, suggesting at least an interformational erosion interval. This, apart from the faulting, provides a convenient horizon for tentatively dividing the Kuabgen group into an upper and a lower part, the former being that already described.

The highest known member of the lower part is the above mentioned very fossiliferous shale adjacent to the fault in the Wok Feneng. A thickness of about 120 feet is exposed, with the top missing, consisting of relatively soft dark-grey shales, medium to thick bedded, silty and slightly micaceous at the top A zone perhaps 20 feet thick near the bottom contains several thin bands teeming with fossils, some with belemnites, others with large *Inoceramus* and *Buchia malayomaorica.* (Sample 215.)

Below this are about 20 feet of greensands interbedded with grey to purple-grey shales containing pyrite, belemnites, ammonites, and pelecypods (sample 219); then about 100 feet of hard thin-medium bedded flaggy silty shales and fine grained sandstones, sometimes alternating; finally grading down into a thick sandstone formation, mostly fine grained at the top and becoming coarser downwards to finish as dominantly gritty arkose conglomerates some 900 feet thick, the lowest beds seen. There are several grit beds and shale bands interspersed through the sandstones, one important dark-grey shale member near the bottom being 110 feet thick and containing *Inoceramus.*

The conglomerates are hard, cemented, well consolidated, and generally massive bedded, consisting principally of angular to sub-angular clear quartz fragments with sub-angular pebbles up to 8 inches through of coarse pink granite with clear quartz and large pink felspars, some pink felspar and rare small well rounded pebbles of grey quartzite and hard grey sandstone. There are many thick beds of grey argillaceous sandstone which weather purplish and constitute the vehicle for numerous immense landslides, especially along the Bol River the north bank of which is really a great dip-slope whose foundations are being eroded away continuously by the swift waters of the Bol.

The total thickness of the lower Kuabgen is 2,330 feet minimum, making a total for the group of 4,040 feet observed, with an unknown amount of section missing through faulting and the

base not having been reached. The Wok Feneng was traversed with greater and greater difficulty upstream until what seemed like a definite reversal in dip was encountered Subsequent observations from Kuabgen Range indicated that this was not the case and that no more than a small local fold occurs there However, at the point reached the gradient of the stream exceeds 300 feet per mile and no pebbles were found other than the sandstones and conglomerates already known. Consequently it is considered that very little if any more section is exposed in the Feneng, and at any rate nothing below the conglomerate outcrops there.

The Kuabgen group is even less fossiliferous generally than the Feing group, but macro-fossils are visible on several horizons. Belemnites were seen in two zones in the upper part, both in the Wok Feneng; one from dark-grey flaggy argillaceous siltstone or fine sandstone about 1,000 feet down in the section, the other from hard dark thin bedded shale containing concretions, about 400 feet higher, where they are associated with *Inoceramus*. Glaessner has determined the belemnite from the latter outcrop to be *Belemnopsis gerardi*.

As mentioned previously a shale band about 20 feet thick in the upper part of the lower Kuabgen group contains thin very richly fossiliferous layers. One of these is teeming with belemnites recognized by Glaessner as *Belemnopsis gerardi*, another is practically built up of pelecypods which he considers are *Buchia malayomaorica* with some large *Inoceramus* sp. Immediately underlying are alternating beds one of which, a pyritic concretionary greensand, contains *Belemnopsis* cf. *indica*, *Meleagrinella braamburiensis* and a few indeterminate ammonites.

The thick shales towards the bottom of the exposed section contain *Grammatodon* (*Indogrammatodon*) *virgatus* and a few *Inoceramus* sp.

Glaessner considers that the palaeontological evidence demonstrates an Oxfordian age for the *Buchia-Belemnopsis* beds and a possibly Callovian age for the underlying *Echinotis* and *Grammatodon* beds, making the Kuabgen group generally Upper Jurassic.

Since the base of the Kuabgen group has not been reached anywhere in this part of New Guinea, there is no direct evidence of the character of the immediately underlying rocks. However, since the lowest strata seen consist almost entirely of a considerable thickness of fresh looking and only slightly rounded granite derivatives which become coarser grained as the section is descended, it is believed that the granite surface which furnished these sediments was situated near-by and that in all probability granite basement underlies the Kuabgen conglomerates at no great depth.

This situation occurs in the Chimbu area, some 250 miles to the east, where Noakes (1939) reports that a very thick section of Mesozoic rocks rests directly on granite, palaeontological examination setting the age of the basal sediments at Upper Jurassic.

Igneous Boulders.

Numerous well rounded pebbles and boulders of a dense igneous rock with large augite or hornblende crystals in a light-grey ground mass, possibly andesitic, occur in the Bol River and further down in the Wok Feneng. The source of the boulders was not found but as they do not occur as components of any of the sedimentary rocks in the area, it is inferred that they come from dykes in the upper Bol valley.

## Notes on Mesozoic Geological History.

Mesozoic rocks are known from a number of widely scattered points in New Guinea, principally along the Central Highlands. These occurrences have been listed by Glaessner (1943) who has discussed their correlation. He suggests that in Jurassic times, part of western and central New Guinea was a geosynclinal area which extended possibly into eastern New Guinea.

The information generally is very scanty, a big proportion of the occurrences being known only from stream pebbles and very few good sections having been inspected. Most of the information so far obtained is barely sufficient to give an idea of distribution, and provides little basis for deductions concerning geological history.

Although still meagre, more is known perhaps of that part of the Central Highlands which includes the Feneng area than of any other region in New Guinea.

Data presented in this paper indicate that the oldest Mesozoic sediments seen in the Feneng area, arkose conglomerates grits and sandstones of the lower Kuabgen group, Callovian in age, in all probability lie very close to granite basement. In the Feneng region generally, Callovian fossils have been reported from the Strickland River about 50 miles south-east of the Wok Feneng, from the Sepik River about 50 miles north, and from the Digoel River 70 miles north-west. Pre-Callovian also has been reported from the Strickland.

The character of the lower Kuabgen group suggests that the immediately adjacent land surface had been eroded down to granite basement prior to the beginning of Kuabgen deposition. Hence it seems likely that the Feneng area itself was dry land during most of lower Mesozoic times at least. The distribution of Upper Jurassic rocks in the region suggests that a Mesozoic geosyncline was developed mainly north of the Feneng area and

that the granite land mass which provided the lower Kuabgen sediments lay to the south and south-west, possibly connected with the Australian shield.

The subsidence which initiated the Upper Jurassic marine transgression in the Feneng area did not continue uniformly, fluctuations in rate of subsidence being denoted by irregular alternations in lithology, especially of the middle to upper Kuabgen deposits. The conglomerates at the base of the upper Kuabgen group are evidence of at least one important oscillation which raised the lower Kuabgen sufficiently to undergo erosion.

There is a big gap in the Feneng record between Oxfordian and Albian, the lowermost Cretaceous and possibly the uppermost Jurassic being absent Representatives of some of the missing stages have been reported from the Sepik River, the Om and the Strickland. Possibly uplift of the southern marginal area of the geosyncline during the early Cretaceous at least, favoured denudation of whatever post-Oxfordian strata may have been deposited, before renewed submergence in Albian time started deposition of the Feing group.

Waterworn pebbles of Kuabgen type occurring in the basal Feing sandstones indicate some erosion of the Jurassic strata, while the general quartz sandstone nature of these basal beds, with frequent subangularity of grains, indicates that once again a granite land area was the principal source of the sediments. This idea is supported also by the abundant glauconite in the Feing group.

Subsidence seems to have been more uniform and widespread in the upper Feing, resulting in the basal sandstones grading into mudstones which persisted, with relatively minor intercalations of sandstone, through a considerable thickness of strata and occupying at least a large part of Cenomanian time.

Another big time gap occurs between the Cenomanian and Tertiary. Here there is some slight evidence of a long period mainly of non-deposition Possibly during this period major regional subsidence resulted in this area being covered by deep water far removed from land and in which conditions were not favourable to abundant marine life.

A striking feature of the whole Mesozoic section in the Feneng area is the universal prevalence in the sandstones and grits of clear quartz grains, most frequently only partially rounded. There seems to be little doubt that the Feing and Kuabgen groups were derived almost entirely from a granitic source, with relatively minor amounts of material eroded from already deposited Mesozoic sediments.

As indicated above, the Feneng area appears to have been located about the southern margin of an Upper Mesozoic geosyncline with a granite land surface extending to the south and south-west. The absence of any appreciable angular discordance

between the lithological units where big time breaks are shown by palaeontological studies, proves that this area was only slightly affected by the intense orogenic movements experienced in other parts of the south-west Pacific at the end of the Jurassic and Cretaceous Periods.

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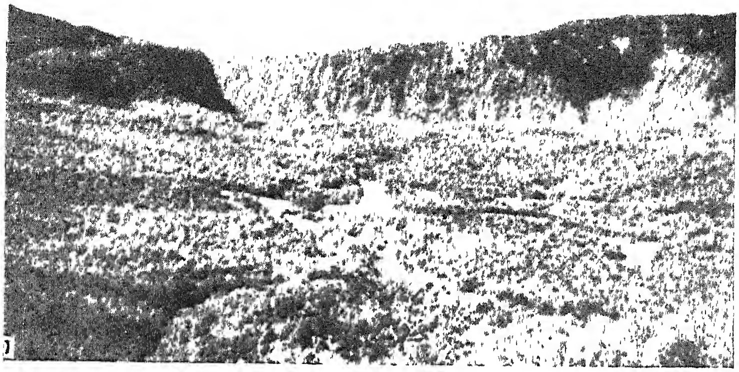
## Explanation of Plate.

PLATE V.

FIG. 1.—Looking south from Observation Hill, showing the Gim Gorge of the Fly River between the Emuk and H Ranges Precipitous scarps 1,500-2,000 feet high held up by Tertiary limestones. Lower, more subdued topography typical of Feing mudstones (Cretaceous).

FIG 2—Topography developed in Kuabgen group. Long dip slopes and strike ridges Melokin Range in middle distance, towering scarp of Kaban Range, Tertiary limestone, in background. View from Kuabgen Range looking east-south-east across Feneng and Bol Valleys

FIG 3—Looking north through the mouth of the Gim Gorge into the Feneng area, showing the almost vertical limestone walls, 1,500 feet high, and the boulder-strewn channel of the Fly River at the base.



[PROC. ROY SOC. VICTORIA, **56** (N.S.), PT. II., 1945.]

# ART. X.—*Mesozoic Fossils from the Central Highlands of New Guinea.*

By M. F. GLAESSNER, Ph.D.

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## Abstract.

Upper Jurassic and middle Cretaceous mollusca from Central New Guinea are described, including genera and species known from the Upper Jurassic of north-western India and of the East Indies (*Buchia-Belemnopsis* fauna), from the Upper Albian and Cenomanian of southern India and from the Aptian-Albian of Australia. Lists of foraminifera are given and the stratigraphic position of fossiliferous Mesozoic sediments of Papua and New Guinea is discussed.

## Introduction.

The samples of fossiliferous rocks and fossils described in the following communication were collected in 1938-1940 by geological field parties engaged in reconnaissance surveys on behalf of Island Exploration Company and Australasian Petroleum Company. These parties were led by Dr. W. D. Chawner, Mr. N. Osborne, and Dr. S. W. Carey. A small number of fossils collected in 1939 by Mr. L. C. Noakes, then Assistant Government Geologist of the Territory of New Guinea, have also been studied.

For detailed accounts of field observations in the Mesozoic sediments of Papua, including localities at which rock samples and fossils were collected, reference should be made to publications by N. Osborne (1944), and S. W. Carey (1944). The author has discussed recently general questions of stratigraphic correlation in a wider area (Glaessner, 1943).

The fossils described in the following account were taken from the Kuabgen group (Upper Jurassic) and the Feing group (Albian-Cenomanian) which form a sequence of strata 7,500 feet thick in the Fly River headwaters in Western Papua, from the two lower divisions of the " Wahgi Series " (Jurassic, Aptian-Albian) of the Chimbu-Mt. Hagen area, Territory of New Guinea, and from the Lower Cretaceous Purari formation on the Middle Purari River, Papua (see map). Type specimens have been deposited in the collection of the Geology Department of Melbourne University, and representative fossils and rock samples will be forwarded to the Commonwealth Geological Collection, Canberra.

The writer wishes to express his gratitude to Mr. N. Osborne and Dr. S. W. Carey for valuable material and useful information placed at his disposal, to Dr. F. W. Whitehouse for the generic determination of one of the fossils, to Dr. N. H. Fisher, former Government Geologist, Territory of New Guinea, for permission to quote from an unpublished report by L. C. Noakes, and to the Directors of the Island Exploration Company and Australasian Petroleum Company for permission to publish this contribution.

## Jurassic Fossils.

### FORAMINIFERA.

A small number of foraminiferal tests representing the genera "*Cristellaria*", *Nodosaria, Dentalina* and *Epistomina* occurs in the dark shales of the Kuabgen group of the Upper Fly River (samples 215, 213). These are generally the most common genera of foraminifera occurring in Upper Jurassic clays and shales.

### MOLLUSCA.

1. **Grammatodon (Indogrammatodon) virgatus** (J. de C. Sowerby).

(Pl. VI., figs. 1*a-b*.)

*Cucullaea virgata* J. de C. Sowerby, 1840. Trans. Geol Soc. (2), vol. 5, pl. 22, figs. 1-2.

*Grammatodon (Indogrammatodon) virgatus*, L. R. Cox, 1937. Proc. Malacol Soc. London, vol. 22, p. 195, pl. 15, figs 8, 9.

*Grammatodon (Indogrammatodon) virgatus*, L. R. Cox, 1940. Pal. Indica., ser. 9, vol. 3, pt. 3, p. 74, pl 2, figs. 22-30.

Material.—A single specimen, almost complete, both valves preserved but distorted by dorso-ventral compression.

Occurrence.—Black shale, lower part of Kuabgen group, about 3,300 feet below the top (sample 252).

Description.—The characters of this specimen agree with *G. virgatus* as redescribed by Cox. The main distinguishing features of the subgenus *Indogrammatodon*, the inequilateral shape and the difference in ornamentation of the two valves are clearly visible. The radial ribs in the left valve are stronger and more widely spaced. The umbones are placed at about the anterior two-fifths of the length. About 18-20 ribs are visible in the left valve anterior to the rounded carina, and about 16 are distinguishable on the anterior half of the right valve, with a few finer riblets intercalated between the 8th to 12th ribs. About 12 less distinct postero-ventral ribs are also recognizable. The posterior area of the right valve bears two or three radial threads

The large number of radial ribs, their shape and distribution and other well preserved characters of ornamentation agree with *G.* (*I.*) *virgatus*, rather than with the similar *G.* (*I.*) *egertonianus* (Stoliczka). As far as distortion does not interfere with measurements, they are in agreement with *virgatus*, particularly the position of the umbones. *G.* (*I.*) *egertonianus* is more inequilateral.

Measurements.—Length of hinge margin 33 mm., umbo about 13-14 mm. from the anterior end of the hinge margin; height uncertain, probably more than 15 and less than 20 mm.

Age.—According to L. R. Cox, *G.* (*I.*) *virgatus* ranges from the *macrocephalus*-beds of the Lower Chari of Kachh, north-western India (Upper Bathonian or Lower Callovian) through the Middle Chari (Callovian) and the *athleta*-beds to the lower Dhosa Oolite of Lower Oxfordian (Upper Divesian) age.

### 2. **Meleagrinella braamburiensis** (Phillips).

(Pl. VI., figs. 2-4.)

*Avicula braamburiensis* nom nud., J. de C. Sowerby, 1829, in: Murchison. Trans. Geol. Soc., (2), vol. 2, p. 323.

*Avicula braamburiensis*, Phillips, 1829. Ill. Geol. Yorkshire, p. 140.

*Pseudomonotis braamburiensis*, Douglas and Arkell, 1932. Quart. Journ Geol. Soc., vol. 88, p. 163, pl. 12, figs. 5, 6.

?*Aucella* sp., Wandel, 1936, N. Jahrb. f. Min., Beil -Bd. 71, (B), p. 461, fig 1*a-c*.

Material.—Numerous closely-packed small single valves, about 24 examined.

Occurrence.—Black sandy shale, with *Belemnopsis* cf. *indica*, lower part of Kuabgen group (sample 219). About 40 feet below the *Buchia*-bed.

Description.—"Left valve moderately flattened, much less inflated than in *Pseudomonotis echinata* (Sow.), ornamented with some 25-30 fine thread-like ribs, which are faintly knotted at long intervals where crossed by some of the more prominent of the indistinct growth lines. The ribs are separated by wide, flat sulci, at least three to four times as wide as the ribs, and between every pair is a still finer secondary rib. The ornament is essentially radial, very little concentric element entering into it. Umbo small, much less tumid than in *P. echinata*, salient about 1½ mm. dorsal to the hinge-line.

Right valve nearly flat, but with surface rising slightly towards the umbo, which is not salient dorsal to the hinge line. Ornament as in the left valve, but more reticulate, owing to the concentric growth lines being more visible Auricles small, the ribs covering them in both valves." (Douglas and Arkell).

Measurements.—Height about 16-17 mm., length about 9-14 mm. (left valves).

The available material from the Jurassic of Central New Guinea agrees well with *M. braamburiensis* rather than with the typical wide-ranging *M. echinata,* mainly in the characters of the left valve which is less inflated, with "essentially radial" ornamentation. The right vales are smooth or show only faint traces of radial threads and weak concentric growth lines. The new specimens also resemble a form considered by Wandel as an "*Aucella*" belonging to the group of *A. malayomaorica* Krumbeck. The strongly-developed angular posterior auricle, the straight hinge margin and the deep, narrow byssal notch agree with *Echinotis* and distinguish these shells from *Buchia.* The concentric ornament is much reduced, as in *M. braamburiensis.*

Measurements.—Height about 16-17 mm, length about 9-14 mm. (left valves).

Age.—*M. braamburiensis* was described from the Lower Oxfordian of England. Wandel's "*Aucella*" comes from the middle and upper part of the Lower Oxfordian of Misol (Demú limestone and Lilintá marly lime-stone) L. R Cox (1940) found the majority of his specimens of *M. echinata* from the Bathonian of Kachh closely resembling *M. braamburiensis.* He states that the stratigraphic difference which exists in England between the typical *M. echinata* (Bathonian) and *M braamburiensis* was not observed in the Indian material.

### 3 **Buchia malayomaorica** (Krumbeck).

(Pl. VI., figs. 5, 6, *7a-b.*)

*Aucella plicata* (non Zittel), G. Boehm, 1911, N. Jahrb. f. Min. (1), p. 13, pl. 2, figs. 1-4.

*Aucella malayomaorica* Krumbeck, 1923, Pal v Timor, Lfg. 12, Abh. 20, p. 65, pl. 2, figs 2-12, 17; pl. 6, fig. 13.

*Aucella plicata* (non Zittel), Trechman, 1923 Quart Journ. Geol Soc., vol 79, p. 266, pl. 17, figs. 4-8.

*Pseudomonotis* sp., Broili, 1924. Wet. Mededeel., vol. 1, p. 10, figs. 10, 11.

*Aucella boehmi* Marwick, 1926. Trans. N Z. Inst., vol. 56, p. 305, pl. 71, figs. 10-13.

*Aucella plicata* (non Zittel), Kruizinga, 1926. Jaarb. Mijnw, vol. 54, Verh., pt. 1, p. 17.

*Buchia boehmi,* Marwick, 1934. Proc. Fifth Pacif. Sci. Congr, p. 949.

*Aucella malayomaorica,* Krumbeck, 1934. N. Jahrb. f. Min., Beil.-Bd. 71, (B), p. 446ff., 462.

*Aucella malayomaorica,* Wandel, 1936 N. Jahrb. f. Min., Beil.-Bd. 75, (B), p. 456, pl. 15, figs. 5, 6; pl. 17, figs. 1-11.

*Buchia malayomaorica,* Teichert, 1940. Journ. Roy. Soc. W. Austr., vol 26, p. 109.

*Buchia malayomaorica,* Glaessner, 1943. Proc. Roy. Soc. Vict., vol. 55, pt. 1, p. 45.

Material—Numerous right and left valves, about 24 specimens examined.

Occurrence.—Black shale with *Inoceramus* and *Belemnopsis gerardi,* top of lower division of Kuabgen group (sample 215), locally forming a shell breccia. Also in dark-red to chocolate-coloured shale, about 2,700 feet above base of Chimbu-Wahgi section (Lower Wahgi valley, Noakes coll., sample 57) and in similar stratigraphic position in green calcareous shale 18 miles east of Mt. Hagen aerodrome (Noakes coll., sample 78). *Buchia malayomaorica* has been described from Timor, Rotti, Jamdena, Ceram, Boeroe, the Soela Islands, Misol, Boeton, East Celebes, Western New Guinea (Itebere R., Kamoendan River headwaters, Amberbaken district) and New Zealand (Locality 1193, West of Waikiekie Stream, Kawhia Harbour).

Description.—This species was fully described by Krumbeck (1923), Marwick (1926), and Wandel (1936) The new specimens agree with these descriptions. The outline of the shell shows little variation. The anterior and posterior margins of the valves are nearly parallel ("forma typica") The approximately rectangular outline in this species differs markedly from the oblique shape of typical representatives of the genus. The surface ornamentation is variable. Krumbeck observed this variability and stated that almost all right valves showed radial as well as concentric ornamentation while only rare left valves had distinct radial ribs In the present material variability of the radial ribs affects both valves about equally.

Measurements.—Adult valves are about 30 mm high and about 20 mm. long, but the ratio is variable.

Age.—Upper part of Lower Oxfordian or lower part of Upper Oxfordian (Approximately zone of *Cardioceras cordatum* ?).

### 4. **Inoceramus** sp.

*Inoceramus* occurs in at least two horizons in the Kuabgen group (samples 215, 213) but the available material is not sufficiently well preserved to permit specific identification. Fragments of large shells resemble *I. haasti* Hochstetter as well as *I. subhaasti* Wandel and *I. galoi* G. Boehm. Fragments of *Inoceramus* occur with *Buchia malayomaorica* in the Chimbu-Wahgi section (Noakes' sample 57).

### 5 **Belemnopsis gerardi** (Oppel).

(Pl. VI., figs. 8, 9*a-b*.)

*Belemnites gerardi*, Oppel, 1865. Pal. Mitt. a.d. Mus. d. Bayer. Staates, pl. 88, fig. 1.

*Belemnites gerardi*, Uhlig, 1910. Pal. Indica, ser. 15, vol. 4, p. 386, pl. 93.

*Belemnopsis gerardi*, Kruizinga, 1921 Jaarb. v h. Mijnw., vol. 49, Verh. pt. 2, p. 163, pl. 1, fig. 1, 3

*Belemnites gerardi*, Broili, 1924. Wet. Mededeel, vol. 1, p. 8, pl. 2, fig. 9.

*Belemnopsis gerardi*, Stolley, 1929. Pal. v Timor, Lfg. 16, Abh. 29, p. 151, pl. 248, figs. 16-32, pl. 249, figs. 1-3

*Belemnopsis gerardi*, Spath, 1933. Pal. Indica, n s., vol. 9, Mem. 2, pt. vi., p. 660ff.

*Belemnopsis gerardi*, Spath, 1939. Pal. Indica, n s., vol. 25, Mem 1, pt. iii., p. 135.

Material.—Four well-preserved specimens and about 20 fragments

Occurrence—Abundant in black shale with *Buchia malayomaorica* and *Inoceramus*, top of lower division of Kuabgen group (sample 215), also in upper division, about 1,100 feet higher (sample 213).

Remarks—This is a controversial species. Without detailed examination of large numbers of well-preserved specimens and comparison with the holotypes of several similar named species which are evidently variable and overlap morphologically, nothing useful can be added to the controversy about the synonymy of this group. The new specimens agree with some of those figured by Uhlig from the Spiti shales (l.c. pl. 93, figs. 7, 9), by Kruizinga from Taliaboe and Mangoeli, Soela Islands, and by Stolley from Timor. Broili figured a specimen from Western New Guinea (Kamoendan River headwaters) as *B. gerardi*. While resembling the present material in its general character it differs in shape, having its greatest width below the middle of the length of the guard, as in *B. taliabutica* (G Boehm). *B. alfurica* G. Boehm and a similar form described by Teichert from Broome, Western Australia, as *B. cf. alfurica* have a deeper ventral groove, a more circular transverse section, slender shape and narrower alveolar part.

*Age.*—Notwithstanding the controversy about the synonymy of *B. gerardi* and the age of its holotype, this fossil is a valuable stratigraphic marker for the Oxfordian in the eastern part of the Sunda archipelago. Abundant occurrence like that observed in the *Buchia-Belemnopsis* bed of the Kuabgen group is recorded from the Wai Galo beds of the Soela Islands. This important fossiliferous horizon is assigned by Spath to the *cordatum*-zone of the Oxfordian and its stratigraphic position is close to that of the Belemnite beds at the base of the Spiti shales in the Himalaya. In his recent discussion of *B. gerardi,* Spath came to the conclusion that its range is Upper Jurassic (and possible Lower Neocomian).

6. **Belemnopsis** cf. **indica** Kruizinga.

cf. *Belemnopsis indica,* Kruizinga, 1921. Jaarb. Mijnw., vol. 49, Verh. pt. 2, p. 171, pl. 3, fig. 1-3.

cf. *Belemnopsis indica,* Stolley, 1929. Pal v. Timor, Lfg. 16, Abh. 29, p 165, pl. 250, figs 7-10.

cf. *Belemnopsis indica,* Kruizinga, 1931. Leidsche Geol. Mededeel., vol. 5, p. 369, 377.

cf. *Belemnopsis indica,* Stolley, 1935. N. Jahrb f. Min., Beil.-Bd. 73, Abt. B. p. 50.

Material.—Two fragmentary rostra, apical portion not preserved.

Occurrence.—Sandy shale, with *Meleagrinella braamburiensis,* lower part of Kuabgen group (sample 219). About 40 feet below the bed with *Buchia* and *Belemnopsis gerardi.*

Remarks.—This species is characterized, according to Kruizinga, by the shape of its rostrum. The greatest width is in the middle, and the dorso-ventral diameter is 20 per cent. shorter than the transverse diameter. These features are clearly recognizable in the two available fragments which are quite unlike any of the numerous fragments of B. gerardi from a slightly higher horizon. They resemble however *B. calloviensis* (Oppel) as figured by Spath (1927, p. 6, pl 1, fig. 7).

Age.—*B. indica* is known from the Oxfordian of Taliaboe and Rotti and the "Lower Oxfordian" of Boeroe, Mangoli and Misol.

## Cretaceous Fossils.

### FORAMINIFERA.

Feing group.—A rich and varied foraminiferal fauna occurs in the argillaceous rocks of the Feing group. Only preliminary determinations are at present available. They indicate clearly late Lower Cretaceous to early Upper Cretaceous age.

The lowest fossiliferous sample (210) contains the following fauna.—

*Trochamminoides* sp.
"*Cristellaria*' sp.
*Marginulina* spp.
*Nodosaria* sp.
*Lagena* sp.
*Pleurostomella* sp.
*Gyroidina nitida* Reuss.
*Anomalina* sp.
*Globigerina infracretacea* Glaessner.

The occurrence of *Pleurostomella* is important as this genus is not known in earlier than late Albian beds. The assemblage does not contain any distinctive Upper Cretaceous elements.

It is followed by a rich fauna occurring in numerous samples from the higher part of the Feing group. This fauna includes:—

*Rhizammina* sp.
*Ammodiscus* sp.
*Haplophragmoides* sp.
*Trochamminoides* sp.
*Ammobaculites* sp.
*Textularia washitensis* Carsey.
*Textularia rioensis* Carsey.
*Dorothia filiformis* (Berthelin).
*Dentalina communis* d'Orbigny.
*Nodosaria affinis* Reuss.
*Nodosaria obscura* Reuss.
*Nodosaria soluta* Reuss.
*Tristix excavata* (Reuss).
*Lenticulina* sp.
*Marginulina* sp.
*Saracenaria* sp.
*Globulina lacrima* Reuss.
*Buliminella* sp.
*Bulimina reussi* Morrow.
*Pleurostomella subnodosa* Reuss.
*Gyroidina nitida* Reuss.
*Anomalina* spp.
*Globigerina infracretacea* Glaessner.
*Globigerina* spp.
*Globotruncana* aff. *appenninica* O. Renz.

The lowest occurrence of this fauna is reported from a horizon 1,300 feet above the base of the Feing group (sample 224). The composition of the assemblage suggests Cenomanian age. Some of its species, particularly *Textularia washitensis* occur also in the shales with Cenomanian ammonites at Mingenda in the Wahgi valley and in "Stage 3" of the Chimbu-Wahgi section (see below p. 166). *Globotruncana* aff. *appenninica*, a single-keeled species of this typical Upper Cretaceous genus, with inflated chambers, appears to be a world-wide marker for Cenomanian. It has not been recorded yet from elsewhere in New Guinea.

2. Purari formation.—The foraminiferal fauna of the Purari formation is generally rather poorly preserved. It appears to be uniformly distributed throughout the sections exposed in Paw Creek (see Carey, 1944). The following preliminary determinations have been made:—

*Rhizammina* sp. (common).
*Ammodiscus* sp.
*Haplophrammoides* sp. (common).
*Dorothia gradata* (Berthelin) (common).
*Lenticulina gaultina* (Berthelin) (frequent).
*Lenticulina* sp.
*Astacolus* sp.
*Vaginulina* sp.
*Planularia* sp.
*Marginulina* spp.
*Nodosaria* sp.
*Lagena apiculata* Reuss.
*Globulina* sp.
*Buliminella* sp.
*Gyroidina* aff. *nitida* Reuss.
*Epistomina* sp.

The general composition of this fauna agrees with assemblages found in the upper part of the Lower Cretaceous (Aptian or Albian). It resembles the foraminiferal fauna of the lower part of the Feing group; *Pleurostomella* and *Globigerina* are however absent from the Purari fauna.

# MOLLUSCA.

## The Mollusca of the Feing Group.

### **Pseudavicula** sp.

Material.—Numerous valves (about 20-30), both right and left, mostly preserved as internal and external casts, with fragments of the shell attached.

Occurrence.—Dark shale of the Feing group (samples 210, 239), about 500 feet above base, with *Parahibolites blanfordi*.

Description.—Shell small, suborbicular, inequilateral, compressed, test very thin, often wrinkled by rock pressure. Umbo small, very little projecting, sub-central in relation to the greatest length of the valve. Dorsal margins straight, antero-dorsal margin long, slightly convex, forming a blunt angle with the broadly rounded ventral and posterior margin. Posterior auricle large, with a distinct dorsal rim, posterior margin convex. Surface covered with numerous blunt radial ribs, unequal in width, with narrow smooth interspaces.

The large size of the anterior portion of the shell appears to be a distinctive feature of these fossils but the available material is not well enough preserved to permit a more detailed description and identification.

Age.—Upper Albian.

### **Inoceramus** sp.

Fragments of large shells representing an undetermined species of *Inoceramus* occur in the type area of the Feing group (samples 212, 239, 209) and also in the Palmer River area, 20 miles east-south-east (Chawner coll., samples 14, 121).

### **Turrilites** aff. **costatus** Lamarck.

Material.—A distorted and partly crushed fragment of a single whorl.

Occurrence.—Feing group, basal part of Narin formation (Chawner coll., Palmer River, sample 115).

Remarks.—This fragmentary specimen resembles *T. costatus* Lamarck and also *T. acutus* Passy which according to Spath is connected with Lamarck's species by innumerable passage forms. *T. costatus* is known from the Cenomanian of Europe, North Africa, Palestine, Zululand, Madagascar and Southern India (Middle Utatur group). *T. acutus* is known from the Cenomanian of France, Northern Germany, North Africa and Natal and the "Vraconnian" of Mexico

### **Parahibolites blanfordi** (Spengler).

(Pl. VI., figs. 10*a-c*)

*Belemnites fibula* (pars), Blanford, 1861, The foss. Cephalop. of the Cret. rocks of S. India. Pal. Indica., ser. 1, p. 3, pl. 1, figs. 14, 16-19, 24-34, 41; pl. 2, figs 5, 6 (non *B. fibula* Forbes).

*Belemnites n.sp.*, Kossmat, 1897. Rec. Geol Survey of India, vol. 30, pt. 2, p. 87.

*Pseudobelus blanfordi* Spengler, 1910. Beitr. z. Pal. u. Geol. Oesterr.-Ung. u.d. Orients, vol. 23, H.3, p. 155, pl. 12, fig. 6, pl. 14, fig. 6

*Parahibolites blanfordi*, Bulow-Trummer, 1920. Fossilium Catalogus i., pt. 11, p. 164.

Material.—A single well-preserved rostrum.

Occurrence.—Dark shale of Feing group, 500 feet above base, with *Pseudavicula* sp and smaller foraminifera (sample 210)

Description —" Guard elongated, compressed, columnar or lanceolate, acutely pointed behind on the frontal aspect. Section oval or oblong. Ventral surface evenly rounded with a very short furrow at the anterior extremity Sides more or less flattened, having in some specimens a shallow sulcation, most distinct in front; marked very distinctly with a double vascular impression, which generally extends the whole length of the guard. The alveolar cavity very acute, and extending in all the specimens examined, considerably more than half the length of the guard It is somewhat eccentric, particularly in very compressed specimens." (Blanford).

Remarks.—The laterally compressed shape, short ventral groove, and well-developed straight lateral lines over the whole length of the Feing specimen agree well with the species described by Blanford as *B. fibula*.

Age.—This species is known only from the Lower Utatur group of southern India, zone of *Stoliczkaia dispar*, Upper Albian (" Vraconnian").

## The Mollusca of the Purari Formation.

A rich fauna of mollusca was obtained by Carey in the area occupied by the sediments of the Purari formation. The majority of samples taken from outcrops contain only smaller foraminifera and other microfossils (holothurian plates, ophiuran vertebral ossicles, ostracodes) and undeterminable echinoid remains. One bed in the upper part of the exposed section is rich in *Exogyra* aff. *couloni* and contains also *Ostrea* sp. and a small number of undetermined lamellibranchs and gastropods. Numerous pebbles and boulders of a blue, hard sandy limestone or calcareous sandstone collected in the creeks in this area are extremely rich in mollusca. This " molluscan bed " has not been seen in situ in the type area of the Purari formation (Paw Creek). Carey (1944) states that "the horizon of the molluscan material cannot be very different from that of the *Exogyra* bed."

Owing to limitations of available time and facilities the present writer has not yet been able to carry out a complete study of this rich fauna. A list of a few distinctive forms follows, and the most abundantly occurring species among them is described, together with the *Exogyra* and a belemnite, a perfect specimen of which was found in a loose block of sandstone.

The fauna includes *Lingula* cf. *subovalis* Davidson, *Trigonia* sp., *Cardium* sp. *Ptychomya* sp., *Pseudavicula papyracea* Etheridge, *Ostrea* sp, *Mytilus* sp, *Nerinea* sp, *Aporrhais* (*Anchura*) cf. *wilkinsoni* Etheridge, ?*Praestriaptychus* sp., *Tetrabelus macgregori* n. sp.

### 1. **Pseudavicula papyracea** R. Ethridge, jun.

(Pl VI., fig. 11.)

" Undetermined bivalve ", R. Etheridge, jun., 1892. Geol. Pal. Queensland, p. 482, pl. 21, fig. 14.

*Pseudavicula papyracea*, R. Etheridge, jun., 1907. Rec. Austral. Mus., vol. 6, No 5, p. 319.

Material —Large numbers of more or less well preserved specimens.

Occurrence.—Abundant in calcareous sandstones rich in mollusca, Purari formation, Paw Creek, and Wabo Creek, Middle Purari valley (not found in situ) Similar forms occur also in " Stage 2 " of the Chimbu-Wahgi section, Lower Wahgi valley (Noakes coll., sample 30).

Description—" Shell suborbicular, delicate and fragile, compressed, posteriorly, alate, test very thin, papyraceous. Left valve convex in the umbonal region, with a sharply-pointed rather elevated umbo. Right valve more depressed than the left and the umbo inconspicuous. Dorsal margins on both sides straight, those anterior to the umbo obliquely inclined, those on the posterior straight; anterior ends small, the margins rounded; posterior alations small, flat, the margins rectangular. Sculpture of microscopic concentric lines" (Etheridge 1907.)

Measurements.—In the majority of examined specimens the height varies between 15 and 30 mm.

Remarks.—The characters of the most abundant lamellibranch of the Purari molluscan fauna appear to agree well with Etheridge's description. The left valve, not figured by Etheridge, resembles his second " undetermined bivalve" (l.c. 1892, pl. 21, fig. 16) although as stated by this author, the umbo is further removed from the anterior margin in the present species. In some specimens the concentric growth lines are fairly well marked. The present writer has been unable to compare his material with Etheridge's type specimens.

### 2. **Exogyra** aff. **couloni** (Defrance).

Material.—Numerous specimens, mostly casts with fragments of the shell preserved. Left valve attached to various molluscan shells.

Occurrence—A distinctive calcareous "*Exogyra*-bed," about 10 feet thick, in the upper part of the Purari formation; Paw Creek area, middle Purari valley. (Samples 130-139.)

Remarks.—The present specimens, although abundant, are rather poorly preserved. They agree in general with the description of *E. couloni* given by H. Woods ("*E. sinuata* Sowerby," H. Woods, Palaeontogr. Soc, vol. 66, 1913, p. 395, pl. 61, fig. 13, text figures 194-214). The only noticeable difference is the absence of any concavity of the posterior margin of the shell. It is generally straight. None of the specimens seen is nearly as large as the largest European representatives of the species (average length about 5 cm.).

Age.—*E. couloni* is a common fossil of the Lower Cretaceous. An *E.* cf. *couloni* was reported by Piroutet from the Lower Cretaceous (Moindou) of New Caledonia.

### 3. **Tetrabelus macgregori** n. sp.

(Pl. VI., figs. 12*a-b*.)

?*Belemnites* sp., R. Etheridge, jun., 1902. Mem. Geol. Survey N.S.W., Palaeont. Nr. 11, p. 46, pl. 9, figs. 3-5.

?*Tetrabelus* sp., F. W. Whitehouse, 1924. Geol. Mag., vol. 59, p. 413ff.

Material.—One large well-preserved rostrum, one small rostrum of similar type, and several fragments which are enclosed in hard rock.

Occurrence.—Tuffaceous and calcareous sandstones of the Purari formation, Paw Creek, Middle Purari valley. Holotype from sample 186, Paw Creek, not in situ. Also in boulders of molluscan sandstone from Paw Creek (samples 65, 107, 109) and Wabo Creek (sample 20).

Description.—The holotype of this species was examined by Dr. F. W. Whitehouse who recognized it as a new species of *Tetrabelus*. Whitehouse (l.c, 1924) established this genus for "clavate belemnites provided with dorso-lateral grooves and lateral lines, having, in addition, independent ventro-lateral grooves. Alveolus normal" In the new species the rostrum is strongly constricted in the post alveolar region and dorso-ventrally compressed, particularly where it expands again to its greatest width. Dorso-lateral grooves well developed, prominent and deep, passing at about one-third of the length of the rostrum into the less conspicuous lateral lines, the connection being not straight but ventrally curved The lateral lines continue nearly to the apex. Ventro-lateral grooves faintly developed in the alveolar region.

Measurements.—Length 100 mm., greatest width 13 mm., dorso-ventral diameter between alveolar region and zone of greatest width 9.3 to 9.6 mm, minimum width in alveolar region 9.8 mm.

Remarks.—The writer was unable to compare the new form with the original of Etheridge's unnamed belemnite from the Aptian of New South Wales. The two specimens appear to be very similar in size and shape but Etheridge's form contracts more rapidly toward the apex. According to Whitehouse it "shows a very long ventro-lateral groove converging towards the dorso-lateral near the apex". This is not the case in the Purari specimens. Whitehouse also states that "from the figure given by Etheridge the two grooves are of almost equal strength, the dorso-lateral however being possibly a little more prominent In *T. kleini* all grooves are of equal impress, while in *T. seclusus* the ventro-lateral is much more distinct than the dorso-lateral." From this description it appears that the new species is different from all known representatives of the genus. If Whitehouse's view of a "morphological progression" from *Dimitobelus*, without independent ventro-lateral grooves, through the known species of *Tetrabelus* is accepted, then the new species should be regarded as the most primitive form.

This species is named after Sir William MacGregor, explorer and administrator of Papua, who discovered the Cretaceous rocks on the Purari in 1894.

## Stratigraphic Conclusions.

### 1. Fossiliferous Mesozoic Rocks of New Guinea.

The Mesozoic stratigraphy and fauna of Netherlands New Guinea were summarized by Zwierzycki (1928, 1931) in his explanations to the geological maps of that territory, and reviewed by Hövig (in: Klein 1937, pt. 2). E. R. Stanley published data on the Mesozoic rocks of the Territory of New Guinea (1923, pp. 30-31) and of Papua (1923A, pp. 25-27). Certain statements on this subject in Stanley's publications require critical comments in order to define more clearly the available data.

The age of the *Alveolina*-limestone on Mt. Wilhelmina in Netherlands New Guinea, which was mentioned by Stanley, is Eocene (Zwierzycki 1928, p. 29). The fossils reported by Richarz from the Torricelli Mountains as Cretaceous (Cenomanian) are Miocene. This was recognized by Schubert and again emphasized by Zwierzycki (1928, p. 25). The "Cretaceous *Alveolina*-limestones" of the Finisterre Mountains on the North Coast of New Guinea are actually known to be Miocene, including Middle Miocene

at the genotype locality of *Flosculinella* Schubert (Kabarang River near Cape Rigny). Stanley was probably misled by references to "chalky" limestones. The *Globigerina*-limestones in the Njau plain on the border between Netherlands New Guinea and the Mandated Territory were reported by Schubert to contain Cretaceous foraminifera, but he pointed out that these fossils are possibly not *in situ*. The "cherts containing *Actinacis sumatrensis*" described by Gregory and Trench from pebbles collected in the Fly River have not been found by Osborne on his recent expedition to the Fly River headwaters. The range of the genus *Actinacis* is now known to extend into the Oligocene The occurrence of fossiliferous Upper Cretaceous "at the head of Karova Creek, a few miles east-north-east of Kerema" has not been confirmed in the course of geological exploration carried out in this area on behalf of Australasian Petroleum Company. Some confusion concerning the locality of Stanley's specimen, which appears to have been lost subsequently, is suspected by the present writer. All fossils found by Everill "in about latitude 7° south on the Strickland River" came from pebbles and the inclusion of this area in the Mesozoic on the geological map of Papua is not justified. Recent work by Noakes revealed evidence for Neogene age of limestones in Northern New Britain for which Cretaceous age had been assumed on lithological grounds and on the evidence of a gastropod cast determined as "*Actaeonella*" (probably *Oliva* sp.).

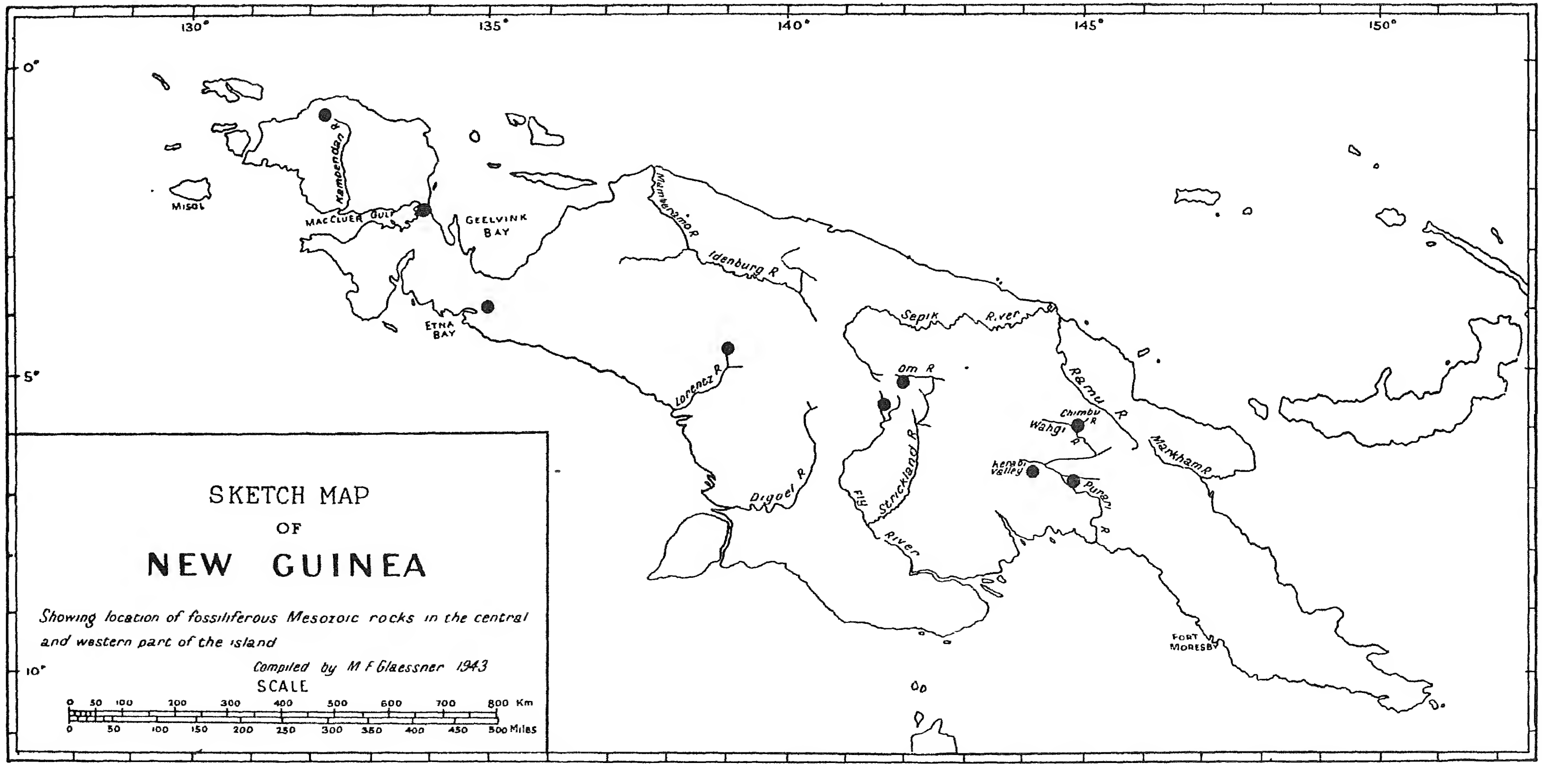
The known pre-Tertiary basement in a wide zone, including the northern coastal ranges of New Guinea, the Bismarck Archipelago, the Solomon Islands, New Hebrides, Fiji, and Tonga consists entirely of metamorphic or plutonic rocks.

The known occurrences of fossiliferous Mesozoic rocks in Papua and the Territory of New Guinea include the headwaters of the Fly, Strickland, and Sepik rivers, some of the country north of Mt. Murray (Kerabi Valley), and on the Middle Purari River, the Wahgi Valley (see map), and areas in the Owen Stanley Ranges.

## 2. The Age of Kuabgen Group.

The fauna with *Buchia malayomaorica* and *Belemnopsis gerardi*:—Abundant occurrence of *B. gerardi* and similar forms, together with large *Inoceramus* is a characteristic feature of Oxfordian strata in the eastern part of the Sunda archipelago. The middle part of the Jurassic sequence on the upper Fly river is therefore considered as Oxfordian. This agrees also with the distribution of *Buchia malayomaorica* at the numerous localities from which this species has been recorded. The same age is assigned to the *Buchia malayomaorica*-horizon of the Chimbu-Hagen area, about 2,700 feet above the base of the Mesozoic section described by Noakes. Pebbles with Oxfordian fossils are known from the Sepik river.

The stratigraphic range of the Kuabgen group:—The oldest Jurassic fossil found in the Fly River section is *Grammatodon virgatus,* which ranges from the *macrocephalus*-beds (Upper


SKETCH MAP
OF
NEW GUINEA
Showing location of fossiliferous Mesozoic rocks in the central and western part of the island
Compiled by M F Glaessner 1943
SCALE
0 50 100 200 300 400 500 600 700 800 Km
0 50 100 150 200 250 300 350 400 450 500 Miles
130°
135°
140°
145°
150°
0°
5°
10°
Misol
Kamoendan R.
MacCluer Gulf
Geelvink Bay
Etna Bay
Mamberamo R
Idenburg R
Lorentz R
Digoel R
Sepik River
Om R
Strickland R
Fly River
Ramu R
Chimbu R
Wahgi R
Kenabi Valley
Purari R
Markham R
Fort Moresby

Bathonian or Callovian) to the *cordatum*-zone (Upper Divesian-Lower Oxfordian). While this range gives no direct evidence of pre-Oxfordian age of the lower Kuabgen beds, the reported occurrence of this species in lower zones of the Upper Jurassic may be significant. Callovian fossils are well known as pebbles from the rivers of the Central Highlands of New Guinea, including the Strickland and Sepik. The species *Meleagrinella braamburiensis* and *Belemnopsis* cf. *indica* from a bed below the *Buchia*-horizon are forms which apparently did not range above the lower Oxfordian. This again agrees with the assumption that the base of the Oxfordian may be above the horizon of *Grammatodon virgatus.* Callovian age of this part of the Kuabgen group is therefore not unlikely. There is little evidence of Middle Jurassic (Bathonian-Bajocian) in this part of New Guinea. It is confined to a report of *Stephanoceras* from the Strickland pebbles.

The upper part of the Kuabgen group contains only *B. gerardi.* The age of this part of the section cannot be determined directly. The occurrence of uppermost Jurassic ammonites in the Sepik pebbles, to which a record of perisphinctids of "uppermost Jurassic or lowest Cretaceous" age determined by Reeside from beds outcropping in the Om River (Strickland headwaters) can now be added (see Osborne, 1944, p. 132) indicates the probability of Tithonian occurring in the area. No definite index fossils of uppermost Oxfordian or Kimmeridgian age have been recorded from the Indo-Pacific region.

The age of the Kuabgen group is therefore Upper Jurassic (possibly Callovian to Tithonian). Some Middle Jurassic may also be present in the vicinity of the Sepik-Strickland divide, in view of the recorded occurrence of *Stephanoceras.*

### 3. The Age of the Feing Group.

The age of the beds with *Parahibolites blanfordi*:—The lower part of the Feing group is characterized by the occurrence 500 feet above the top of the Jurassic of a belemnite known from the Lower Utatur group of Southern India (Upper Albian, *dispar*-zone). The character of the foraminiferal assemblage found in the lower Feing agrees with this age. The lowest part of the Cretaceous section is represented by sandstones from which a loose block containing fragments of belemnites, lamellibranchs, crinoids and echinoids (sample 209) is believed to be derived. As the belemnites could not be freed from the matrix, they remain, unfortunately, undetermined. It is not unlikely that the genus *Parahibolites* is represented among them. A more calcareous portion of this sample shows some slight resemblance with the molluscan bed of the Purari formation. This sandstone block contains pebbles some of which are evidently derived from

the Kuabgen group. A large pebble of black siliceous shale found loose at the same locality contains several specimens of a canaliculate belemnite.

The age of the beds with *Globotruncana* aff. *appenninica*:— The Lower Cretaceous lower part of the Feing group passes gradually upward into more argillaceous beds containing a rich assemblage of smaller foraminifera, including Upper Cretaceous forms such as single-keeled *Globotruncana* with inflated chambers (*appenninica*-type), *Bulimina reussi, Pleurostomella subnodosa,* together with other species known from Albian and Cenomanian (*Gyroidina nitida, Textularia washitensis, T. rioensis*). *Inoceramus* and *Turrilites* cf. *costatus* occur together with this assemblage which has a distinctly Cenomanian character.

## 4. The Age of the Purari Formation.

The Cretaceous beds in the hills north of the Purari River, about 120-136 miles up its course, were discovered by Sir William MacGregor in 1893-4.

Only a preliminary examination of the fossils collected at the same locality by Carey in 1940 has been carried out. The foraminiferal fauna indicates approximately Aptian to Albian age. The fauna of the molluscan bed contains elements related to species from the Tambo and Roma beds of eastern Australia (Upper Albian, Aptian), such as *Lingula* cf. *subovalis, Pseudavicula papyracea, Alaria* cf. *wilkinsoni, Tetrabelus macgregori,* but in the absence of ammonites it is impossible to assign it to definite zones. The Lower Cretaceous affinities of the fauna are strengthened by the occurrence of *Exogyra* cf. *couloni* and of further mollusca resembling Australian Lower Cretaceous forms which, however, have not yet been examined in detail. Most of the larger fossils appear to be derived from the upper 1,000 feet of the Cretaceous sequence which is transgressively overlain by Eocene. If this part of the Purari formation is assigned to the Aptian or Albian, the question arises whether the lower part of the sequence could represent earlier stages of the Lower Cretaceous. The uniform character of the foraminiferal assemblage throughout the sequence makes a very great age difference between the higher and lower beds unlikely.

## 5. Correlation of the Purari, Feing, and Kuabgen Strata.

The Purari formation cannot be considered as an equivalent of the entire Feing group. It is possible, however, that the upper part of the Purari formation corresponds to the lower part of the Feing. The conspicuous molluscan bed of the Purari formation has been reported from a number of widely scattered localities.

A typical specimen was obtained by Mr. Ethell, Patrol Officer, in the course of a patrol between Keuri (Sarugi) Valley and Lake Tebera, 20 miles west of the type locality on the Purari. One hundred and eighty miles further west, on the Strickland River, at the highest point reached by Everill in 1885, G. Barrow collected a pebble of a bluish-green calcareous sandstone with abundant mollusca. A similar rock was found in 1939 by the late L. Vial, then Assistant District Officer, in the Wahgi Valley west of Mingenda.

A detailed study of the Lower Tertiary and Mesozoic sequence in the lower Chimbu and Wahgi Valleys, which was carried out by L. C. Noakes in 1939, proved the existence of a series of sediments over 22,000 feet thick, "in which deposition extends conformably from about Jurassic to Eocene time." (This and the following quotations are taken from an unpublished report by L. C. Noakes, dated July, 1939.) Noakes divided this sequence, which consists predominantly of shales and mudstones, with some sandstones, into five "stages". The lower two and part of "Stage 3" are of interest in conjunction with the present investigation. A dark-red to chocolate shale with *Buchia malayomaorica* and *Inoceramus* was found in "Stage 1" about 2,700 feet above the base of the section. This "stage" consists mainly of slightly calcareous and siliceous shales.

The second "stage" is characterized by an abundance of tuffaceous sandstones most of which are laminated or interbedded with shale. A volcanic agglomerate was taken by Noakes as marking the base of this "stage". Most of the samples are unfossiliferous but fragments of *Ostrea*, a *Pseudavicula* and plant remains occur in the upper 1,500 feet (samples 28-36), suggesting a correlation with part of the Purari formation. "Stage 3" consists mainly of shales and mudstones. "The Mingenda ammonite horizon is considered to lie in the lower half of this stage" (Noakes). This bed, which is exposed on Mingenda Mission aerodrome, contains well-preserved ammonites and *Inoceramus* resembling those reported by E. R. Stanley (1923, p. 26) from the Kerabi Valley north of Mt. Murray. These appear to be approximately of middle Cenomanian age (Whitehouse 1926, p. 279. The writer was informed by Dr. Whitehouse that various published references to a fauna "from the Strickland River" are based on Stanley's specimens). The Mingenda bed and its equivalents in "Stage 3" contain also *Textularia washitensis,* a foraminiferal species known from the upper part of the Feing group.

The resulting correlations are shown in the following table:—

TABLE 1.—Correlation of Fossiliferous Mesozoic Strata in New Guinea.

| | | Fly River Area. | Strickland River Area. | Area between Strickland and Purari Rivers. | Wahgi River Area. | Purari River Area. |
|---|---|---|---|---|---|---|
| | | (Transgressive Tertiary limestones) | | | | (Transgressive Tertiary Limestones) |
| Cenomanian | | Feing Group (3,400 feet) | | Kerabi beds (thickness and sequence unknown) | " Stage 3 " (6,500 feet) | |
| Lower Cretaceous | Albian | | | | | Purari Formation (5,000 feet, base not known) |
| | Aptian | | " Fossiliferous Green-sand " (not known *in situ*) | | " Stage 2 " (6,200 feet) | |
| | Neocomian | | | | ? | |
| Upper Jurassic | | Kuabgen Group (4,000 feet) | Om river beds (thickness unknown) | | " Stage 1 " (4,500 feet) | |

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## Explanation of Plate.

### PLATE VI.

FIG. 1*a-b.*—*Grammatodon (Indogrammatodon) virgatus* (J. de C. Sowerby). Kuabgen Group (Upper Jurassic), Fly River Headwaters, Papua. (Coll. N. Osborne, sample 252.)

FIGS. 2-4.—*Meleagrinella braamburiensis* (Phillips). Kuabgen Group (Upper Jurassic), Fly River Headwaters, Papua. (Coll. N. Osborne, sample 210.) Fig. 2—right valve, figs. 3, 4—left valves.

FIGS. 5*a-b,* 6.—*Buchia malayomaorica* (Krumbeck). Kuabgen Group (Upper Jurassic, Oxfordian), Fly River Headwaters, Papua. (Coll. N. Osborne, sample 215.) Fig. 5*a*—right valve, external view; fig. 5*b*—same valve, internal view; fig. 6—left valve, internal view.

FIG. 7.—*Buchia malayomaorica* (Krumbeck). Wahgi Series. "Stage 1" (Upper Jurassic, Oxfordian), Lower Wahgi River, New Guinea. (Coll. N. Noakes, sample 57.) Left valve, external view.

FIGS. 8, 9 *a-b*—*Belemnopsis gerardi* (Oppel). Kuabgen Group (Upper Jurassic, Oxfordian), Fly River Headwaters, Papua. (Coll. N. Osborne, sample 215.)

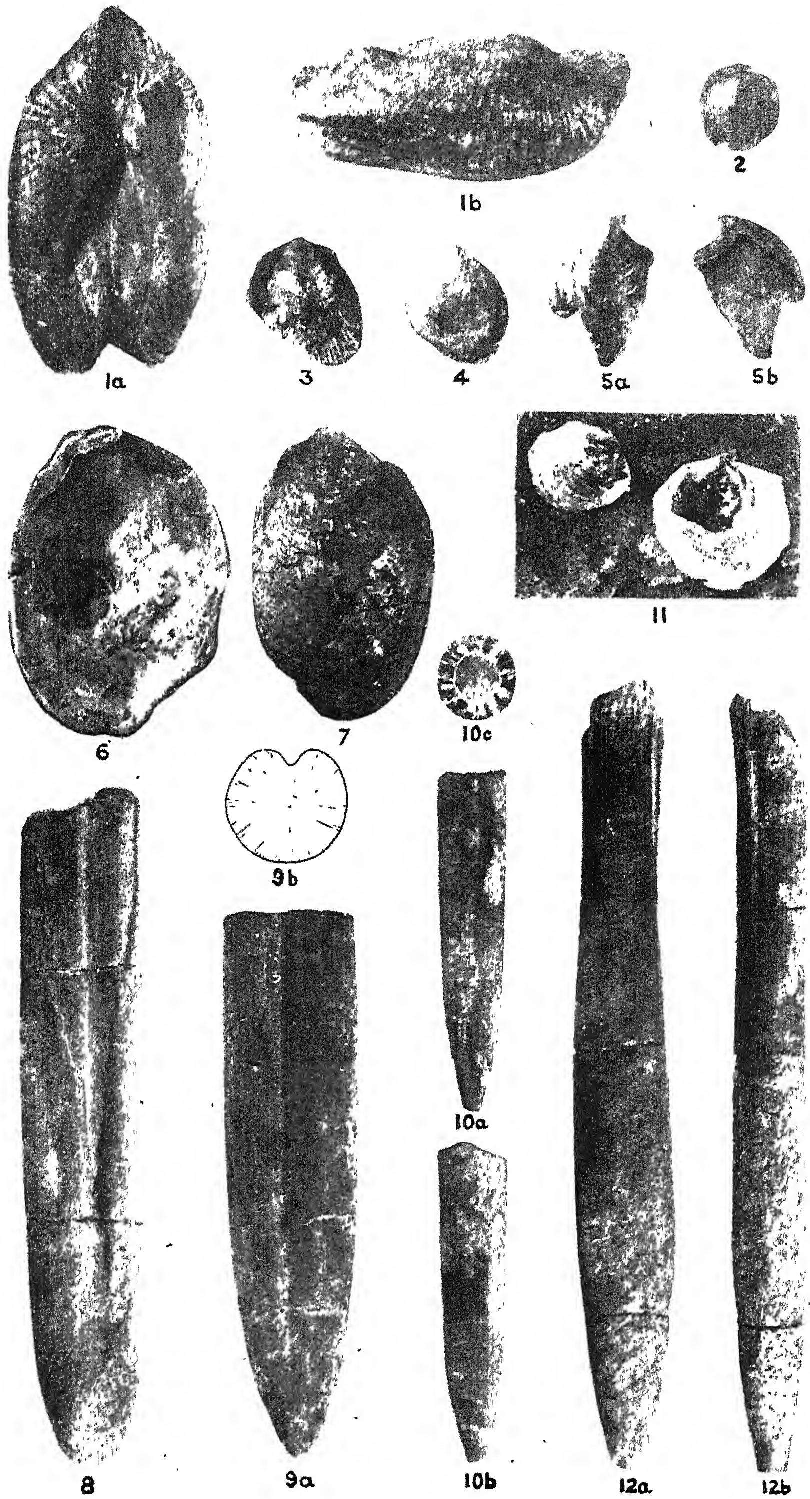
FIGS. 10 *a-c.*—*Parahibolites blanfordi* (Spengler). Feing Group, lower part (Upper Albian). Fly River Headwaters, Papua. (Coll. N. Osborne, sample 210). Fig. 10*a*—ventral view. Fig. 10*b*—lateral view. Fig. 10*c*—alveolar view.

FIG. 11.—*Pseudavicula papyracea* (R. Etheridge, jun.). Purari Formation (Aptian-Albian), Wabo Creek, Purari River, Papua. (Coll. S. W. Carey, sample 22)

FIG. 12*a-b.*—*Tetrabelus macgregori* n sp. Holotype. Purari Formation (Aptian-Albian), Paw Creek, Purari River, Papua. Coll S. W. Carey, sample 186, Melbourne University, Geol. Department Reg. No. 1876).

Photographs by Miss M. L. Johnson, Melb. Univ. Geol. Dept.

All figures approximately natural size.


1a
1b
2
3
4
5a
5b
6
7
11
10c
9b
8
9a
10a
10b
12a
12b

[PROC. ROY. SOC. VICTORIA, **56** (N.S.), PT. II., 1945.]

ART. XI.—*Trilobita of the Family Calymenidae from the Palaeozoic Rocks of Victoria.*

By EDMUND D. GILL, B.A., B.D.

[Read 9th December, 1943; issued separately 30th June, 1945.]

## Summary.

Four new species of trilobites—*Calymene bowiei, C. killarensis, Gravicalymene hetera,* and *G. kilmorensis*—are described, *Gravicalymene angustior* (Chapman) re-described, and notes provided on other forms. Descriptions and maps of new fossil localities are given The bearing of these determinations on stratigraphy is discussed.

## Introduction.

Trilobites of the genera treated in this paper are known in Victoria only from Upper Silurian and Lower Devonian rocks. They comprise the following species:—

| *Species.* | *Age* | *Stratigraphical Series.* |
|---|---|---|
| *Calymene bowiei* sp nov. | Lower Devonian | Yeringian |
| *C. killarensis* sp. nov. | Lower Devonian | Yeringian |
| *Gravicalymene angustior* (Chapman) | Lower Devonian | Yeringian |
| *G. hetera* sp nov. | Upper Silurian | Melbournian |
| *G. kilmorensis* sp. nov. | ?Upper Silurian | ?Melbournian |
| *G.* cf. *kilmorensis* sp. nov. | Upper Silurian | Melbournian |
| *Flexicalymene* sp. | ?Upper Silurian | ?Melbournian |

The determinations of fossils in this paper supersede lists previously given (Gill 1938, 1939).

## Systematic Descriptions.

### Family CALYMENIDAE H. Milne Edwards, 1840.

### Genus CALYMENE Brongniart, 1822.

Genotype **Calymene blumenbachi** Brongniart, 1822.

Chapman referred a trilobite from Moonee Ponds Creek, Melbourne, to the above genotype (Chapman 1914, p. 219; 1915, p. 166). The specimen, which consists of thorax and pygidium only, is in the National Museum (reg. No. 452), but as the cephalon is not present, a determination is not attempted. In the 1914 paper (p. 228) *C. blumenbachi* is also recorded from "Upper Yarra". This is apparently the same specimen as was later described as *C.* cf. *blumenbachi* (Chapman 1915, p. 166, Pl. XV., fig. 11). This specimen is in the National Museum, comes from Section 12, Parish of Yering (which in this case is "Flowerfield" Quarry—Gill, 1939), and is No. 1862 of the Geological Survey of Victoria collection. Unfortunately, the preservation is poor, and determination is not attempted. Chapman also recorded "*C.* cf. *tuberculata* Salter" from Kilsyth, near Croydon

(Chapman, 1907, p. 239; 1914, p. 228), which species has since been re-named *C. nodulosa* (Shirley, 1933, p. 53). This specimen (also housed in the National Museum) consists of a few segments of the thorax only, and a determination is not attempted. Selwyn (1855-6) and Smyth (1874, p. 34) record *C. tuberculata* from "Upper Yarra". This is probably the specimen in the National Museum (reg. No. 451) which is complete but ill preserved, and labelled as being from "Yering, Upper Yarra". The matrix suggests that it originates from "North of Lilydale". The specimen does not admit of precise determination by modern standards. "*Calymene* sp." has been recorded from numerous localities, but in most instances the specimens on which the determinations were based cannot now be traced.

## **Calymene bowiei**, sp. nov.

(Plate VII., figs. 1, 2, 6.)

Type Material.—The internal cast of a cranidium and external mould of same (syntypes) in the National Museum, Melbourne (reg. Nos. 14504 and 14505), collected from fawn mudstone at Syme's Homestead, Killara (locality 33).

Age.—Yeringian Series—Lower Devonian.

Description.—Cephalon strongly convex; of the profile shown in fig. 1A. Glabella very convex, being raised well above the level of the fixed cheeks. Glabella much wider posteriorly than anteriorly, i.e., markedly bell-shaped in outline; does not overhang pre-glabellar field; projects well forward ot the fixed cheeks. Posterior glabella lobes large, squarish in outline, and joined to the middle part of the glabella by narrow bridges which are lower in level than the lobe. The bifurcated furrows in front of the posterior lobes leave small protuberances or interlobes between the posterior lobes and the middle ones. The second or middle lobes are markedly smaller than the posterior ones. They are stumpy, but not flattened on the ends as in *C. killarensis*. Opposite the second lobes the fixed cheeks draw in towards the glabellar lobes to form buttresses, but these are not flattened on the tips as they are in *C. killarensis*. The anterior lobes are small, and consist only of dorso-ventral ridges on the sides of the main body of the glabella. There are no fourth lobes. Main body of glabella much higher than lobes. Eyes opposite middle lobes. "Antennary" pits occur in the floor of the axial furrows opposite where the fourth lobes usually appear. The axial furrows are deep, wide in front, and narrow behind the buttresses. Sutures much the same as in *C. killarensis*. The inner margins of the fixed cheeks run directly posteriorly till they draw in towards the glabella to form the buttresses opposite the middle lobes. From the buttresses to the intramarginal furrows the margins curve outwards to give the general bell-shaped appearance of the glabella region. The pre-glabellar field is short, shallow, and

recurved. The recurved margin is thin, and is directed forwards and slightly upwards (fig. 1A). Posterior intramarginal furrows broad; posterior walls a little steeper than the anterior walls. Occipital ring narrows at its extremities, which turn in towards the corners of the fixed cheeks. Genal angles rounded.

Length of holotype cranidium.—21 mm.

Width from genal angle to centre of glabella.—25 mm.

Comment.—The cephalon is tuberculated, but the precise nature of the ornament is not clear because of a layer of iron oxide over the external mould (paratype). *C. bowiei* is readily distinguished from the genotype (*C. blumenbachi*). The former has a bell-shaped glabella as against the squarish outline of the latter. In the genotype, the axes of the glabella lobes run transversely whereas in the new species they are directed forwards at an angle of about 20° to the transverse. The pre-glabellar field of *C. bowiei* (fig. 1A) is of the type of *C. aspera* (*vide* Shirley, 1936, pl. XXX., fig. 10) rather than that of *C. blumenbachi* (*vide* Shirley, 1933, pl. 1, fig. 3).

A few specimens have been noted in which the pre-glabellar field is more upturned than in the holotype. A sufficient range of specimens has not been procured yet, however, to enable one to determine whether this is a varietal difference, or one due to slight compression. The free cheeks are missing from the holotype, but

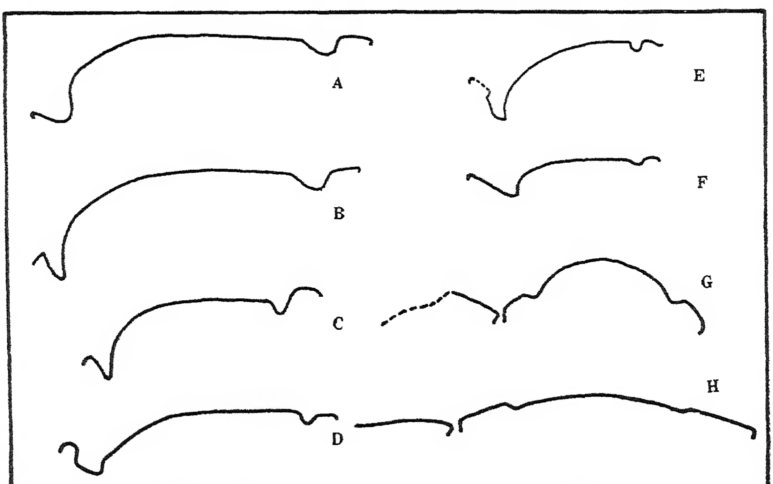



FIG. 1.—Longitudinal median profiles of the cephala of *A Calymene bowiei* sp. nov., *B C. killarensis* sp. nov., *C Gravicalymene angustior* (Chapman), *D G. hetera* sp. nov., *E. G. kilmorensis* sp. nov., *F. Flexicalymene* sp.; transverse profiles through the second glabellar lobes of the cephala of *G. Calymene bowiei* sp. nov., *H. C. killarensis* sp. nov, showing contrast in tumidity.

the general outline suggested by the cranidium is that of one tending towards a triangular shape. *C. bowiei* is named after Mr. Bowie, manager of the Killara estate, who directed the writer to the fossil locality from which the holotype was obtained. Specimens of *Beyrichia* and *Stropheodonta bipartita* (Chapman) occur on the same piece of rock as the type.

## **Calymene killarensis,** sp. nov.

(Plate VII., figs. 8, 3, 4.)

Type material.—The internal cast of a cranidium (holotype) in the National Museum, Melbourne (reg. No. 14506), collected from the bluish-grey shale of Syme's Tunnel, Killara (locality 34).

Age.—Yeringian Series—Lower Devonian.

Description.—Cephalon moderately convex; of the profile shown in fig. 1B. Glabella broad (compare the genotype), overhanging the axial furrows; projects well forward past the fixed cheeks. Four lobes on each side, reducing sharply in size posterior-anteriorly. First lobes almost quadrangular, and connected with the main body of the glabella by bridges which are almost as elevated as the lobes themselves. The main body of the glabella, the bridges, and the lobes form a more or less continuous arch, and contrast in this respect with *C. bowiei* (figs. 1G, H). Second lobes elongated, and flattened on the ends, which are in juxtaposition with buttresses on the fixed cheeks; these second lobes are very noticeably directed forwards, making an angle of about 30° with a line joining the posterior margins of the eyes. Third lobes small, with strong furrowing behind, but shallow furrow in front. Fourth lobes consist of small bulges on sides of glabella, but there are definite furrows in front of and behind these lobes. There are small, rather sharp intermediate lobes between the first and second lobes. Large "antennary" pits lie in the axial furrows beside the fourth lobes. The preglabellar field is short, shallow, and recurved. The recurved part is thin, and projects outwards and upwards at an angle of over 45° with the horizontal (fig. 1B). Eyes opposite second lobes. Axial furrows moderately wide in front of the buttresses, and narrow behind them. Sutures begin just above genal angles and curve in towards the eyes, become almost parallel with the posterior margin of the cephalon when nearly to the eyes; from the eyes the sutures run straight forward to the anterior margin of the cephalon. Posterior intramarginal furrows broad; posterior walls a little steeper than the anterior walls. Occipital ring narrows at the extremities, which turn in towards the corners of the fixed cheeks. Genal angles rounded. Small pieces of the external mould obtained when clearing the fossil of matrix showed the cephalon to have been ornamented with a fine granulation.

Measurements of holotype.—Length of cranidium, 20 mm.; width of genal angle to centre of glabella, 25 mm.

Comment.—The examination of a number of specimens suggests that the axial furrows narrow slightly with age. The thorax is not known. Occasional pleurae are found but no complete thorax has yet been discovered, although the species is quite common at Killara, after which place the fossil is named. Pygidia are common, and probably belong to the same species. They are broad and very convex, with deep axial furrows. There are seven axial rings, and five pleural ribs, the last of which is parallel to the axis. The first four are bent backwards and are grooved distally for about half their length. The pygidium is closely and finely granulate. The cast and mould from which this description of the pygdium has been made, have been lodged in the National Museum (reg. Nos. 14511 and 14512).

The new species is comparable with *C. blumenbachi* which it resembles in its large sub-rectangular glabella. The chief differences are:—(1) The frontal lobe of the glabella does not overhang the pre-glabellar field as in *C. blumenbachi.* (2) The first lobes are even more quadrilateral in the new species than in the compared one. The second lobes, like those of *C. blumenbachi,* " when viewed from above show a papillate outline as if reaching out to the buttress on the fixed cheeks " (Shirley, 1933, p. 60). but much more so, and instead of being directed transversely, they are directed forwards as described. Judging from Shirley's figures (1933, pl. 1), the fourth lobe on our species is much better developed.

Occurrence.—*Calymene killarensis* has been collected by the author from Syme's Tunnel, Killara (loc. 34), and Syme's Homestead, Killara (loc. 33). A crushed specimen from the road cutting near the limestone quarry at Seville (loc. 38) probably belongs to this species. Chapman (1908, p. 269) records *Calymene* sp. from the Seville limestone (loc. 37). A plasticine impression of this mould shows that the specimen has buttresses opposite the second, and therefore belongs to the genus *Calymene sensu lato.* However, the preglabellar field is not preserved. These localities are shown on fig. 2, the numbers following on those previously used (Gill, 1940).

## Genus GRAVICALYMENE Shirley, 1936.

### Genotype **Gravicalymene convolva** Shirley, 1936.

When Shirley established the sub-genus *Gravicalymene,* the genotype was the only species known, and this came from the Upper Bala of Britain. Since then four other species have been referred to this genus, and another is now added in this paper.

When describing the Baton River (N.Z.) Beds, Shirley (1938) referred *Calymene angustior* Chapman to this genus, and also *C. australis* Etheridge and Mitchell, which he thought was almost certainly synonymous with the former. The present writer referred a new species, *Gravicalymene cootamundrensis* to this genus (1940), and later referred *Calymene malounkaensis* Mansuy to it, and suggested the elevation of Shirley's sub-genus to generic rank (Gill, 1942, p. 45).

Diagnosis of Genus *Gravicalymene.*—Calymenidae without papillate glabellar lobes, or buttresses on the fixed cheeks. Glabellar outline bell-shaped. Pre-glabellar field recurved with roll-like edge. Eyes opposite, or slightly anterior to, second lobes. Cephalic margin entire. Thorax (where known) of thirteen segments.

Range of Genus.—Ordovician to Devonian.

Occurrence in Victoria: Three species of this genus are known from Victoria, viz., *G. angustior* (Chapman), *G. hetera* sp. nov., and *G. kilmorensis*, sp. nov.

### **Gravicalymene angustior** (Chapman).

(Plate VII., figs. 5, 10.)

*Calymene angustior Chapman*, 1915, pp. 164-166, Pl. XV., figs. 8-10

*Calymene australis* Etheridge and Mitchell 1917, pp. 481-486, Pl. XXIV., figs. 1-3, ?4, 6-7.

*Calymene (Gravicalymene) ?angustior* Shirley, 1938, p. 487, Pl. XLIV., fig. 17.

*Gravicalymene angustior* Gill, 1942, p. 45.

The following is a re-description of this species from the holotype, and (where indicated) from the paratype presented by Chapman.

Carapace.—Measurements approximately 54 mm. long and 39 mm. wide. The carapace is damaged and so precise measurements are not possible. Widest across genal angles, and tapering to the posterior end of the pygidium.

Cephalon.—Sub-semi-circular and about a third length of carapace.

Narrow, bell-shaped glabella projecting a little beyond the fixed cheeks, with three distinct and a fourth incipient lobes on each side, reducing sharply in size posterior-anteriorly. Glabella tumid, elevated above fixed cheeks, and of the profile as drawn in fig. 1c. Pre-glabellar field (seen only in paratype) with roll-like thickened edge, which is somewhat more thickened opposite the axial furrows. Eyes slightly anterior to the middle of the second lobes.

As the anterior margin of the holotype has been destroyed, the following measurements to give the proportions of the cephalon are taken from the paratype. However, the genal angles of the paratype are obscured by matrix, and right free cheek is displaced. There has been a slight oblique crushing of the cephalon.

Length of paratype cephalon, 14·5 mm.

Width of paratype cephalon, 30 mm.

Length of glabella, 10 mm.

Width of glabella across third lobes, 7 mm

Width of glabella across first (posterior) lobes, 10 mm.

A hypotype (Pl. VII., fig. 5), consisting of a cephalon (National Museum, reg. No. 14507), is now added, providing the following features:—Eyes situated about a quarter of the distance from the axial furrows to the margin of the free cheeks. Genal angles widely rounded. Free cheek suture commences in middle of the genal "angle", and proceeds to a point level with the posterior margin of the eye and half way between the margin of the free cheek and the eye, then proceeds to the posterior margin of the eye. From the anterior margin of the eye the suture proceeds to the anterior border of the cephalon with a slight outward curve. Cephalon finely granulated with granules of different sizes (this is also seen in the paratype). The hypotype is from Ruddock's Quarry (location 20).

Thorax (described from holotype).—Consists of thirteen segments. Axis approximately semi-circular in cross-section, and elevated well above the pleural areas. The axial rings have a prominent knob on each side of the axis. The axis with these knobs occupies a third of the width of the thorax. Pleurae fairly flat until at about three-quarters of their length from the axis, where they are bent sharply downwards. Each pleuron is deeply grooved. The free ends of the pleurae are rounded and curled forwards a little.

Pygidium (described from holotype).—As in the thorax the axial area is elevated well above the pleural areas. The axis tapers back evenly and carries six axial rings. The pleural ribs are streamlined backwards and are grooved distally for a little more than half their length. Well-marked furrows occur where the pleural areas join the axis.

Comment.—*Gravicalymene angustior* is very much like, and therefore presumably closely related to *G. cootamundrensis*, with which it differs in the following points:—

1. The cephalon is semi-circular with widely rounded genal angles in Chapman's species, whereas the compared species has a sub-quadrilateral cephalon with much less rounded genal angles. The cephalon is very convex in the former, and flat in the latter.

2. The free cheeks are wide, and the eyes near the glabella in Chapman's species, whereas in the compared species the free cheeks are narrow, and the eyes nearer the outer margin of the cephalon.

3. The carapace is much smaller and narrower in *G. cootamundrensis* than in *G. angustior.*

Chapman's species has obvious affinities with *G. interjecta* (Corda) of Étages F and G in Bohemia (Barrande, 1852, p. 570). *G. angustior* has a different pre-glabellar field and general profile; the trifurcate furrow between the first and second lobes described in *G. interjecta* is not present. It is interesting to note this link with the Bohemian facies in Europe. *G. angustior* also appears to be comparable with *G. malounkaensis* (Mansuy) from Indo-China (Mansuy, 1916, Pl. IV., figs. 4*a*-*c*). Shirley (1938) included *Calymene australis* (Etheridge and Mitchell) in the synonymy of *G. angustior* and commented (p. 487), "From an examination of the figures and description of *C. australis* (Etheridge and Mitchell), the New Zealand material appears to be identical: the authors specially mention the thickened margin of the pre-glabellar field and the lack of buttresses on the fixed cheeks. They also express a doubt whether their species is really separable from *C. angustior* of Chapman." The new data for *G. angustior* given in this paper (the nature of the genal angles and facial sutures) may be paralleled by Etheridge and Mitchell's fig. 2, Plate XXIV. In the synonymy given above, figure 4 on Etheridge and Mitchell's Plate XXIV. is questioned because it appears to have a sub-quadrilateral cephalon reminiscent of *G. cootamundrensis.* It is hoped to clarify the relationships of these species after the war when the types become available again.

Chapman (1915, p. 166) records this species from reddish sandstone in the "Range on E. side of commonage, Kilmore". This specimen is in the National Museum (the number 1208 is printed on it in red paint), and is described hereunder as *Flexicalymene* sp.

Etheridge (1899) records "*Calymene*" from Cooper's Creek, Gippsland. This fossil (Geol. Survey No. 178) has suffered compression, but no doubt belongs to *G. angustior.* No. 174 was determined by Etheridge as "*Calymene* sp.", but was retained for further study according to the note in the G.S.V. register. It is

therefore presumably still in the Australian Museum, Sydney. The G.S.V. register states that No. 178 now figured (Plate VII., fig. 10), is the same as No. 174.

*Occurrence.*—*Gravicalymene angustior* is known in Victoria from the following localities:—Cooper's Creek, Walhalla; Ruddock's Quarry (loc. 20); Ruddock's Corner (loc. 21); and North of Ruddock's (loc. 39). Figure 2 shows the exact situation of the three last-named localities. The species has also been recorded from the Australian Capital Territory (Woolnough, 1939), but the specimen has not been examined by the writer.

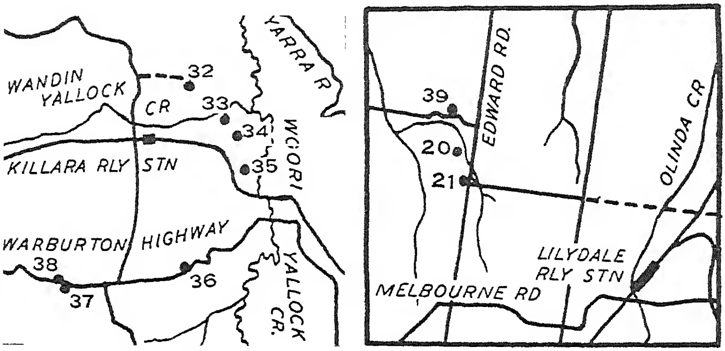



FIG 2.—Fossil localities of the Killara District and north-west of Lilydale.

## **Gravicalymene hetera**, sp. nov.

(Plate VII., fig. 12.)

In the National Museum, Melbourne, (reg. No. 14508), there is a cranidium in bluish-grey, indurated, fine-grained sandstone from Kilmore East, presented by L. C. Parker, Esq., on 12th July, 1924. This fossil has been selected as the holotype for *G. hetera*, to which also should be referred the fossil figured by Chapman (1915, Pl. XV., fig. 10) from locality "Bb20, Kilmore Creek, north of the special survey." The holotype has been distorted a little by lateral pressure.

Description.—The fossil is near *G. angustior*, but differs in the following respects:—

(1) The pre-glabellar field is conspicuously wider and deeper than in *G. angustior*; the rolled "lip" is thinner and sharper than in the compared species.

(2) The glabella does not extend forward as far as it does in *G. angustior*, nor is it elevated high above the fixed cheeks as in that species. The profile is given in fig. 1D. The new species has

fourth incipient lobes as in *G. angustior,* but the "antennary pits" appear to be placed further forward. The measurements of the holotype are:

Length of cephalon, 14 mm.
Width from genal angle to centre of glabella, 20 mm.

Comment.—The Australian species of *Gravicalymene* form a compact group suggesting local evolution of the species. The occurrence of *G. angustior* in the Lower Devonian of New Zealand (Shirley, 1938) suggests some shallow sea connexion with that area as these trilobites show by their structure, the lithology in which they occur, and the fauna with which they were associated, to be of littoral habitat. The occurrence of *Gravicalymene* in Indo-China is interesting as suggesting connexion with that area.

## **Gravicalymene kilmorensis,** sp. nov.

(Plate VII., fig. 9.)

Type Material.—The internal cast of a cranidium (holotype) in the National Museum, Melbourne, reg. No. 14509, from Kilmore East, presented by G. L. Pentreath, esq., 12th July, 1924. The matrix is a bluish-grey, fine-grained, indurated sandstone.

Description.—Cephalon shorter in proportion of width to length than *G. angustior.* Glabella bell-shaped and squat, with three distinct lobes and incipient fourth lobe on each side reducing sharply in size posterior-anteriorly; does not overhang pre-glabellar field; front of glabellar approximately level with forward extensions of fixed cheeks. Axial furrows very open and wider anteriorly than posteriorly. Pre-glabellar field recurved with small subsidiary ridge on roll-like edge. Profile as in fig. 1E. Edge of pre-glabellar field not thickened opposite axial furrows as in *G. angustior.* Eyes opposite second lobes, and much nearer axial furrows than margin of cephalon. Free cheek sutures pass more directly to the posterior margin of the eye than they do in *G. angustior.* Thorax and pygidium unknown.

Comment.—*G. kilmorensis* differs notably from *G. angustior* in (1) the squat proportions of the glabellar; (2) the wide axial furrows; (3) the presence of a subsidiary ridge on the pre-glabellar field, and its lack of thickening opposite the axial furrows; (4) the straighter course of the post-ocular part of the free cheek sutures.

The fossil is decorticated, leaving no indication of the nature of the surface ornament (if any). It is named after the town in the vicinity of which it was collected.

The generic position of this fossil presents an interesting problem. *Gravicalymene* has no subsidiary ridging on the pre-glabellar field according to the original diagnosis of the genus. The pre-glabellar field of the holotype of *G. kilmorensis* was slightly damaged immediately in front of the glabella when the specimen was being cleared of its matrix. However, the nature of the profile, as shown in fig. 1E, is still clear to one side of this point. Shirley's *Gravicalymene* and *Flexicalymene* closely approximate to one another. The description "Thorax 13 segments; glabella outline bell-shaped; pre-glabellar field recurved; axial furrows slightly contracted at each glabellar furrow" would apply equally to the above two genera according to Shirley's diagnoses. The only distinguishing feature in such an instance would be "recurved without subsidiary ridging" as against "recurved with roll-like edge". The fossil now described as *G. kilmorensis* has a recurved pre-glabellar field, but with a flattened slope as shown in the profile. *Diacalymene* (*vide D. drummockensis* in Shirley, 1936, p. 391) is characterized by the development of a subsidiary ridge in the pre-glabellar field, but the new species cannot be referred to *Diacalymene* as that genus possesses papillate second lobes. Shirley states (1936, p. 392) that such features as the character of the pre-glabellar field "must be used with caution and only in combination with other characters of the skeleton". Because of its strong affinities with species of *Gravicalymene,* our new species is doubtless best accommodated in that genus.

## **Gravicalymene** spp.

(1) *Gravicalymene* cf. *kilmorensis,* sp. nov. A specimen in the National Museum (reg. No. 14510) from the Moonee Ponds Creek (Melbournian), collected by Mr. Spry, 5/10/22, belongs to the genus *Gravicalymene* (Pl. VII., fig 7). It is not sufficiently well preserved to make determination certain, but it is probably *G. kilmorensis,* sp. nov.

(2) From Locality 9, allotment 10, Parish of Redcastle, Dr. D. E. Thomas collected specimens of *Gravicalymene* (Geol. Surv. reg. Nos. 38006, 38007, 37974, 37989) which belong, apparently, to yet another species. The great thickness of the rolled edge on the pre-glabellar field is a notable character. The material is not considered good enough on which to erect a new species.

(3) Two specimens of a species of *Gravicalymene,* very much like *G. angustior,* have been collected by the writer from Syme's Tunnel, Killara (loc. 34). However, the glabella stretches further forward than in the species named, the edge of the pre-glabellar field is thinner and sharper, and in size they are very

much smaller. *Calymene* (*sensu lato*) is common at this locality, but the above are the only two specimens of *Gravicalymene* yet found in the district.

## **Flexicalymene** sp.

(Plate VII., fig. 11.)

Chapman (1915) referred a trilobite from reddish sandstone from "range on east side of Reserve of Commonage, Kilmore" to *G. angustior.* This fossil was collected by the Geological Survey in 1903, and is now housed in the National Museum (reg. No. 1208). The specimen is an exfoliated cranidium with a short glabella much narrower in front than behind. The glabella is produced forward of the fixed cheeks. The very wide and high pre-glabellar field is the most conspicuous character of this fossil. The cephalon is 11 mm. long, and the pre-glabellar field occupies 3 mm. (more than a quarter) of the length. The pre-glabellar field is directed forwards and upwards at an angle of 25°–30° to the horizontal. The profile is as shown in figure 1F. The anterior edge of the pre-glabellar field is rounded, but without the "draught-stopper" edge so characteristic of *Gravicalymene.* Like *Gravicalymene* and *Flexicalymene* this fossil has no buttresses opposite the glabellar lobes, and the fixed cheek margins draw in slightly opposite the inter-lobal furrows.

The main features of this form are distinct, and indicate it to be a new species, but the present specimen is scarcely good enough to be made into a holotype. This is the first record of this genus from Australia. Shirley described *Flexicalymene* as a sub-genus, and elsewhere it has been raised to generic status. This lead is followed here. but it is noted that *Flexicalymene* and *Gravicalymene* closely approximate to one another, and that the differences between these genera are not as great as the differences between others of the sub-genera proposed by Shirley.

## **Stratigraphical Considerations.**

The genera *Gravicalymene* and *Flexicalymene,* which are closely related, were described originally by Shirley from the Ordovician of Great Britain (Llandeilo and Bala Beds). Both genera are now known from the Silurian. The former genus is also known from the Lower Devonian, and the latter from beds which are either high in the Silurian or low in the Devonian sequence. The range in time of these genera has therefore been considerably extended.

Another point of interest is the geographical distribution of some of these species. *Gravicalymene angustior* has been recorded from both Australia and New Zealand. A related species has been recorded from Cootamundra, New South Wales (Gill, 1940*a*), and a similar species occurs in the Lower Devonian of Indo-China (Mansuy, 1916). The fauna described by Mansuy has other similarities with our Victorian one. *Styliolina* occurs there as it does in Victoria (Gill, 1941), and a shell figured on his Pl. V., fig. 10), is very like our *Chonetes robusta* Chapman. Mansuy, in 1919, described further fossils from that part of the world. His *Chonetes ningpoensis* is reminiscent of our *Chonetes cresswelli* Chapman. The spiriferid of Mansuy's Pl. 5, fig. 6, is very like an undescribed species from Lilydale

From wide areas of the world and from different stratigraphical horizons, writers have claimed to have found *Calymene blumenbachi* Brongniart. Shirley (1933, p. 62) considers that most of these determinations should be looked upon with suspicion. It appears that in this group a high mutation rate obtained, and numerous closely related forms resulted. Shirley (1936) has described some of the forms closely related to *C. blumenbachi*, and in the present paper it has been shown that *Calymene killarensis*, sp. nov., belongs to this gens. The separation of this series of related forms into distinct species will greatly assist stratigraphical as well as palaeontological studies. A similar review is needed with such brachiopods as *Atrypa reticularis* and *Leptaena rhomboidalis*.

## Fossil Localities.

The location of the fossil localities is shown in fig. 2. The numbers are continued from those given previously (Gill, 1940*b* and 1942).

32. "Killara Quarry" is a disused quarry in quartzitic sandstones (with a few interbedded shales) at the end of a disused road. *Anoplia australis* has been collected from there, and as this brachiopod is known only from beds of Yeringian age, the Killara Quarry beds are regarded as Yeringian.

33. "Syme's Homestead".—The first reference to this locality is in Gill, 1939. The fossils were obtained from an old water race near the Wandin Yallock Creek in front of the homestead of the Killara estate. The matrix is a fawn mudstone which has yielded a very rich Yeringian fauna.

34. " Syme's Tunnel ".—This locality is a tunnel which was mined for the purpose of storing apples in the days before cold storage. The rocks are bluish-grey shales which are weathered often to a brownish colour near the surface. As far as can be ascertained, this locality is that which the early Geological Survey records refer to as " Junction of Woori Yallock and Yarra ".

35. " Syme's Quarry " is just below the manager's house on the Killara estate, and was opened up in 1936 to provide stone for private roads on the estate. It consists of the same kind of rock as seen at locality 34 and is on approximately the same strike.

36. " Warburton Highway, Killara " was mentioned in Gill, 1941, p. 152. The locality is a road cutting where whitish mudstones, sometimes coloured red with iron oxide, outcrop. *Styliolina* is abundant.

37. " Seville Limestone " is a disused quarry on the south side of the Warburton highway on the east side of Seville. Except where the rock is weathered the fossils are very difficult to extract, as the " limestone " contains about 60 per cent. silica. Chapman (1908) has recorded fossils from this locality.

38. " Seville cutting " is a long cutting on the Warburton highway immediately west of locality 37. Shales and sandstones outcrop with occasional fossiliferous bands. West of this point to where the bedrock disappears under the igneous rocks of Mt. Dandenong, the outcrops appear to be unfossiliferous.

39. " North of Ruddock's " is a low road cutting north of locality 20. The matrix and fauna are the same as at localities 20 and 21.

Bb20 is a Geological Survey locality so marked on Quarter Sheet 4 SW, where a note refers to the presence of "*Calymene*". Harris and Thomas (1937, p. 77) refer to the presence at Bb20 of *Monograpti* comparable with forms found in the Melbournian beds.

## Acknowledgments.

For access to materials and many other courtesies I am indebted to Professor H. S. Summers of the Geology Department, University of Melbourne, Mr. D. J. Mahony, M.Sc., and Mr. R. A. Keble, F.G.S., Director and Palaeontologist respectively of the National Museum, and Mr. W. Baragwanath of the Geological Survey of Victoria. The photographs are the work of Mr. L. A. Baillôt, of the Melbourne Technical College.

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## Description of Plate.

PLATE VII.

FIGS 1, 2, 6—*Calymene bowiei* sp. nov. 1 and 2 internal cast and external mould respectively, × 1½ approx. Fig. 6 is part of the glabella in fig. 1 enlarged to show nature of ornament as seen on internal cast.

FIGS 3, 4, 8—*Calymene killarensis* sp. nov. Figs. 3 and 4 are the internal cast and external mould respectively of a pygidium believed to belong to this species Fig 8 is the holotype cranidium × 2.

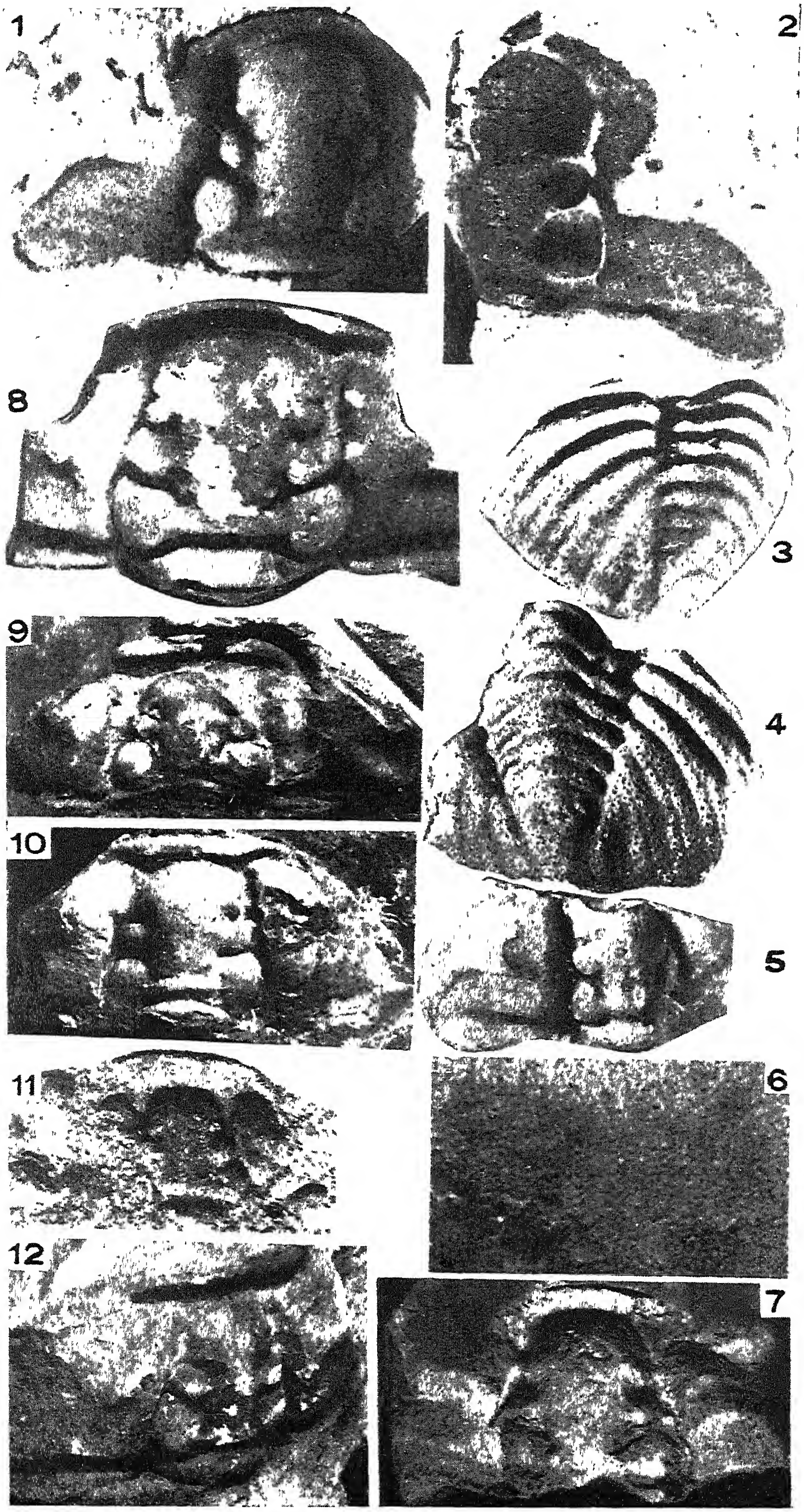
FIGS. 5, 10.—*Gravicalymene angustior* (Chapman). Fig. 5 is the hypotype showing position of the eye and the nature of the suture between the free and fixed cheeks Fig. 10 is a compressed cephalon referable to this species from Cooper's Cr., Gippsland.

FIG. 12—*Gravicalymene hetera* sp nov. Holotype, × 2.

FIG. 9.—*Gravicalymene kilmorensis* sp. nov. Holotype, × 2.

FIG. 7.—*Gravicalymene* cf. *kilmorensis* sp. nov. Specimen from Moonee Ponds Creek × 2.

FIG. 11.—*Flexicalymene* sp. × 2.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[PROC. ROY. SOC. VICTORIA, 56 (N.S.), PT. II., 1945.]

# ART. XII.—*Recent Foraminifera from Barwon Heads, Victoria.*

By W. J. PARR, F.R.M.S.

[Read 9th December, 1943; issued separately 30th June, 1945.]

## Introduction.

Up to the present, only one paper, the well-known one by Mr. Frederick Chapman in the Journal of the Quekett Microscopical Club for 1907, has been published giving a general account of the foraminifera found on the coast of Victoria. While Mr. Chapman's work has been supplemented by descriptions given of a number of species by the present writer, either alone or in

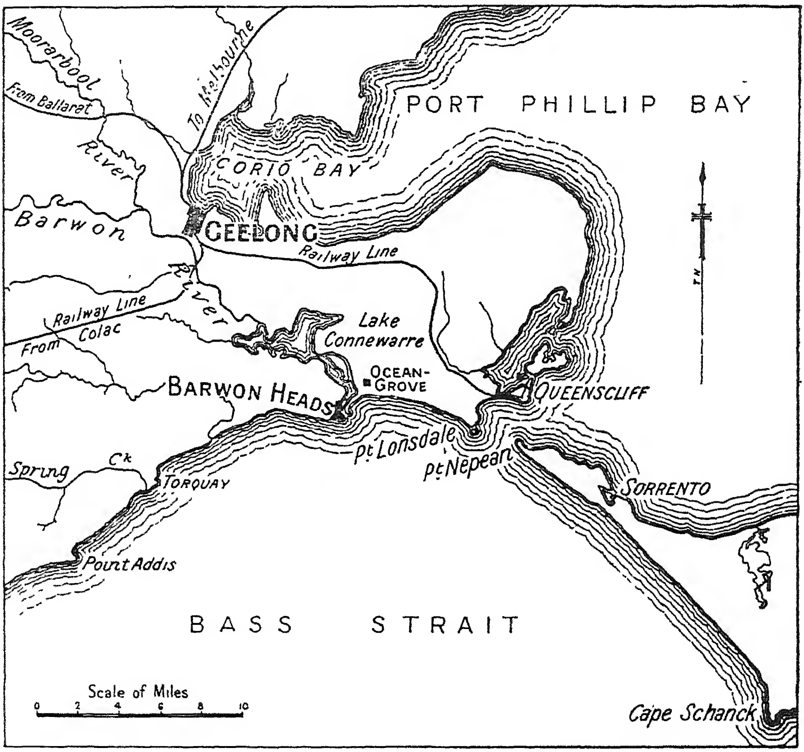



FIG. 1.—Locality Plan of Barwon Heads District.

collaboration with Mr. A. C. Collins, in papers published in this Journal during the years 1930, 1932, and 1937, it has for some time been evident that there are still many new or unrecorded foraminifera occurring in Victorian waters. Practically all of these were found in a number of shore gatherings made at Barwon Heads over a period extending from 1932 until 1943 by Mr. W.

Baragwanath, the Director of the Geological Survey of Victoria, and his daughter, Miss Betty Baragwanath, and kindly made available to me. Apart from the occurrence in the gatherings of practically all of the previously recorded species from Victoria, they provide so much new information on our coastal foraminifera that the following notes have been prepared.

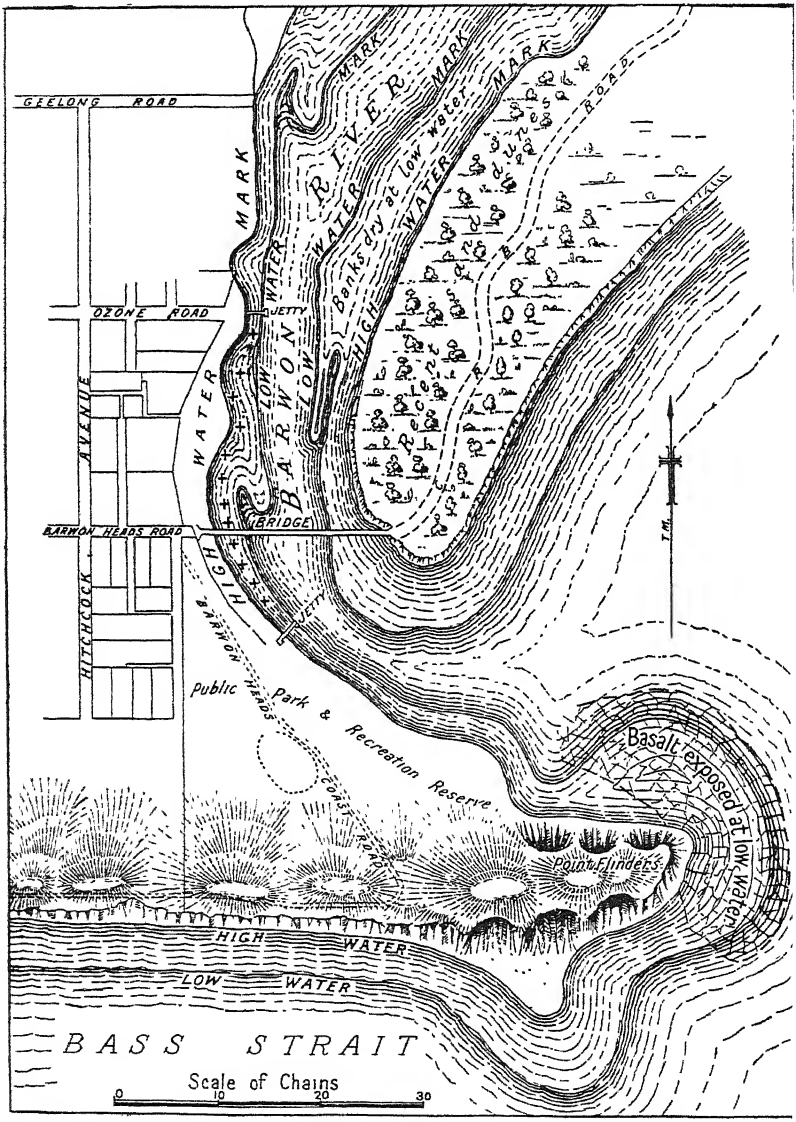



FIG. 2.—Sketch Map of Barwon Heads, showing area from which collections were mad indicated thus +.

The township of Barwon Heads is situated on the west side of the mouth of the Barwon River, about six miles west of the entrance to Port Phillip Bay. Between the township and the shores of Bass Strait is the mass of dune limestone, resting on Older Basalt, known as Mt. Colite, which rises conspicuously above the sand dunes which extend for many miles on either side along the coast.

Inland, the Barwon River widens to form Lake Connewarre, on the northern shores and part of the floor of which are deposits of fossiliferous marls of Middle Miocene age. These deposits extend seawards and outcrop on the sea floor at Ocean Grove, a little north-east of the mouth of the Barwon River.

The Barwon River is subject to tidal influence up to a point above the head of Lake Connewarre and the material collected by Mr. Baragwanath has been deposited by the tide on the sandy beach which forms the west bank of the river over a distance of from 20 to 30 chains inland from its mouth.

As might be expected with material collected over so many years and under varying conditions of weather and tide, there is some difference in the number and variety of the foraminifera present in the various gatherings. While the decision to describe the foraminifera was made so late that those from each gathering were not kept separate with a record of the conditions prevailing at the time of collection, it can be stated that, with the following exceptions, the species in each gathering, while varying in abundance, were the usual forms occurring on a sandy bottom in shallow water on the Victorian coast. On one occasion, specimens of *Tretomphalus*, which had clearly drifted in from the open sea, occurred in great numbers, while, on another, numerous examples of a new species of *Webbinella*, an adherent genus, which was not found in any other gathering, were met with. Two or three gatherings were noteworthy for the occurrence of many exceptionally fine specimens of the rare genus *Delosina*, which has since found to be widely distributed in Bass Strait.

A source of difficulty in dealing with the foraminifera has been the presence in the gatherings of fossil species derived from the Tertiary deposits to which reference has been made. These fossil foraminifera are usually so perfectly preserved that their appearance does not differ from that of Recent specimens and they can accordingly only be distinguished by comparison with those occurring in the local Tertiary deposits. After excluding

all fossil and doubtful species, the number of forms recognized as of Recent origin is 142, including 14 which are described as new. To avoid the necessity of giving the synonmy of every species, references to literature are given only when the species has not been previously sufficiently dealt with in publications which are readily available. With these exceptions, the references will be found in one of the following publications:—


BRADY, H. B., 1884.—Report on the foraminifera dredged by H.M.S. "Challenger" during the years 1873-1876.—Rep. Voy. *Challenger*, Zoology, vol. 9.

CHAPMAN, F., 1907.—Recent Foraminifera of Victoria: Some Littoral Gatherings. *Journ. Quekett Micr. Club*, ser. 2, vol. 10, pp. 117-146, pls. 9, 10.

CUSHMAN, J. A., 1918-1931.—The Foraminifera of the Atlantic Ocean. *U.S. Nat. Mus.*, Bull. 104, pts. 1-8.

PARR, W. J, 1932—Victorian and South Australian Shallow-Water Foraminifera, Part I. *Proc. Roy. Soc. Vic.*, n.s. 44 (1), pp. 1-14, pls. 1, 2; Part II. *Ibid.*, pt. 2, pp. 218-234, pls. 21, 22.

PARR, W. J., and COLLINS, A. C., 1937.—Notes on Australian and New Zealand Foraminifera. No. 3. Some Species of the Family Polymorphinidae. *Proc. Roy. Soc. Vic.*, n.s. 50 (1), pp. 190-211, pls 12-15.


It may be noted here that I now believe that the species recorded in my 1932 papers as being from "Williamstown. Silty mud. (Collected many years ago by the late J. Gabriel)" were not of Recent origin, but were from fine washings, of Middle Miocene age, from one of the bores put down in the Williamstown district in search of brown coal. The specimens of *Discorbis margaritifer* recorded at the same time from shore sand, Point Lonsdale, are also now regarded as being from the Middle Miocene deposits in the vicinity of Ocean Grove. Examples of this species occur commonly in the Barwon Heads shore gatherings, where there can be no doubt of their fossil origin.

To Mr. and Miss Baragwanath, I desire to express my sincere thanks for collecting and making the material available for examination. The assistance of Mr. Arthur Kennedy, of the Mines Department, who made the drawings illustrating the paper is also gratefully acknowledged. I am also indebted to Dr. M. F. Glaessner for his advice on the identification of several of the species.

The types and other specimens are in the writer's collection, and will later be deposited in the National Museum, Melbourne.

## Systematic List of Species.

### Family AMMODISCIDAE.

1. Ammodiscus mestayeri Cushman (Pl. VIII., figs. 1, 2).

*A. mestayeri* Cushman, 1919, Proc. U.S Nat. Mus., 56, p. 597, pl. 74, figs. 1, 2.

This species is represented by ten small examples. It was described from off the Poor Knights Islands, off the east coast of New Zealand, and is stated by Cushman to be distinguished by its few coils and protuberant proloculus.

### Family SACCAMMINIDAE.

2. Proteonina spiculifera Parr (Refs., Parr, 1932, p. 218).

Two specimens similar to those previously figured by the writer from Point Lonsdale, Victoria. The form and wall structure of the test of this species suggest that it may be merely the detached chambers of *Reophax distans*, var. *pseudodistans*, which, like the preceding species, was described by Cushman from off the Poor Knights Islands. No specimens showing an opening at both ends or consisting of more than one chamber have, however, been found and, in the absence of these, the reference to *Proteonina* is retained.

3. Webbinella bassensis, sp. nov. (Pl. VIII., figs. *3a-c*).

Test adherent, plano-convex, circular in outline, usually with a slight rim around the base; chamber single, undivided, consisting of a hemisphere of chitin which supports the weakly-cemented wall of very fine particles of quartz; dorsally the wall is thin, but it thickens towards the base, where in addition to forming the marginal flange it extends underneath for a short distance to cover part of the chitinous floor; no general aperture; colour very pale fawn. Diameter, 0·5 mm.

There are over 80 specimens, all of which are detached from the object to which they were adherent during life. The present occurrence appears to be unique, as the genus usually occurs in small numbers in comparatively deep water attached to stones and shell fragments. The appearance of the Barwon Heads specimens suggests that they were adherent to marine algae. Usually the chitinous lining is preserved and the protoplasmic body has in many cases collected into a brown, rounded mass on the transparent floor of the test.

*W. bassensis* does not closely resemble any previously described species of *Webbinella*. For assistance in its identification, I am indebted to Mr. Edward Milton, F.R.M.S., of Torquay, England, who has also kindly forwarded examples of an undescribed English Recent species of *Webbinella* for comparison.

## Family LITUOLIDAE.

4. Haplophragmoides canariensis (d'Orbigny) (Refs., Cushman, 1920, p. 38).

There are seven examples of the normal form of this species.

## Family TEXTULARIIDAE.

5. Textularia sagittula Defrance (Refs., Brady, 1884, p. 361).

Four typical specimens.

6. Textularia conica d'Orbigny (Refs., Cushman, 1922, p. 22).

A typical example.

7. Textularia pseudogramen Chapman and Parr.

*T. gramen* Brady (*non* d'Orbigny), 1884, p. 365, pl. 43, figs. 9, 10. Cushman, 1924, Carnegie Inst. Washington Publ. No. 342, p. 15, pl. i., figs. 7, 8.

*T. pseudogramen* Chapman and Parr, 1937, Aust. Antarctic Expedn., 1911-14 Sci. Repts., Ser. C, vol. I., pt. 2, p 153.

Several examples. This species is common in Bass Strait. As a holotype was not designated when it was described, I now select the original of fig. 9 of Plate 43 of the "Challenger" Report as the type specimen. This was from "Challenger" Stn. 162, off East Moncoeur Island, Bass Strait, 38-40 fms.

## Family TROCHAMMINIDAE.

8. Trochammina inflata (Montagu) (Pl. VIII., figs. 4*a*, *b*). (Refs., Brady, 1884, p. 338.)

Many typical specimens. *T. inflata* is one of the group of foraminifera which will tolerate brackish water, and on the Victorian coast it appears to be most at home under these conditions, as it is common at the mouth of Kororoit Creek, near Williamstown, and at the mouth of the Barwon River, but is rare elsewhere.

## Family VALVULINIDAE.

9. Clavulina multicamerata Chapman (Refs., Parr, 1932, p. 4).

One specimen. This species is usually more common in Victorian shore sands.

10. EGGERELLA sp. (Pl. VIII., fig. 5).

The only specimen found is probably a new species, but more material is required to determine this. The characters of the specimen, which has a length of 0·35 mm., are shown by the figure. The test, except for the final chamber which is white, is warm brown in colour.

Family VERNEUILINIDAE.

11. GAUDRYINA (PSEUDOGAUDRYINA) HASTATA Parr.

*G. hastata* Parr, 1932, p. 219, pl. 22, figs. 40 *a, b*.

*G. (P.) hastata*: Cushman, 1937, Cushman Lab. Spl. Publ. No. 7, p. 95, pl. 14, figs 7, 8.

Several worn examples.

Family OPHTHALMIDIIDAE.

12. PLANISPIRINA (?) BUCCULENTA (Brady) (Pl. XII., figs. 1*a, b*).

*Miliolina bucculenta* Brady, 1884, p. 170, pl. 114, figs. 3 *a, b*.

*Planispirina bucculenta*. Schlumberger, 1892, Mém. Soc. Zool. France, 5, p. 208, text-figs. 2-4, pl. 8, figs. 6, 7.

There are several examples which, in external characters, are close to Schlumberger's figs. 6 and 7, as well as a number of smaller, irregular, biloculine specimens. This species, which was described from deep water in the North Atlantic, has, at different times, been referred to "*Miliolina*," *Planispirina*, and *Triloculina*, but Schlumberger's figures of sectioned specimens show that the internal structure is not the same as that of any of these genera. Wiesner (1931, Deutsche Südpolar Expedn. 1901-1903. XX. Zool., p. 107, pl. 15, fig. 178) has figured what appears to be this species under the name of *Miliolinella subrotunda* (Montagu), var. *trigonina* Wiesner. The genotype of *Miliolinella*, a genus described by Wiesner in the same work, is *Vermiculum subrotundum* Montagu, the internal structure of which is not fully known, but the megalospheric form, as figured by Sidebottom (1904, Mem. Proc. Manchester Lit. Phil. Soc., vol. 48, No. 5, p. 8, text-fig. 2) from the Eastern Mediterranean, shows a resemblance to the stages following the central disc of the microspheric form of *P.? bucculenta* as figured by Schlumberger. Until the growth stages of the microspheric form of *M. subrotunda* are known, the position of *Miliolinella* is uncertain and I have accordingly referred Brady's species doubtfully to *Planispirina* to which the information available suggests that it is most closely related.

13. NUBECULARIA LUCIFUGA Defrance (Refs., Brady, 1884, p. 134).

Several small examples.

## Family MILIOLIDAE.

14. QUINQUELOCULINA DILATATA d'Orbigny (Refs., Cushman, 1929, p. 26).

There are several examples of this West Indian species.

15. QUINQUELOCULINA LAMARCKIANA d'Orbigny (Refs., Cushman, 1929, p. 26).

In his notes on this West Indian species, Cushman states that, in the West Indies, there are two forms which may possibly be distinct. Both have a smooth surface, but in one the peripheral angle is acute and the surface smooth and polished, while in the other the peripheral angle is usually more blunt and the surface dull. The Barwon Heads specimens are similar to the second form. This is common on the Victorian coast.

16. QUINQUELOCULINA SUBPOLYGONA, sp. nov. (Pl. XII., figs. 2*a-c*).

Test about $1\frac{1}{2}$ times as long as broad; chambers distinct; sutures slightly depressed; each chamber polygonal in cross-section, the periphery concave, usually with a projecting, sometimes undulate, carina at either angle; apertural end extended into a short neck, aperture more or less quadrate, with an everted lip and a single bifid tooth; surface dull.

Length 1·0 mm., breadth, 0·6 mm., thickness, 0·4 mm.

This is the commonest species of the genus on the south coast of Australia. It has been confused with *Q. polygona* d'Orbigny, from the West Indies, but has a shorter, more strongly carinate test than that species and is also less regularly built. Another species which resembles *Q. subpolygona* is *Q. sulcata* d'Orbigny, as figured by Cushman (1932, U.S. Nat. Mus., Bull. 161, p. 28, pl. 7, figs. 5-8) from off Fiji. This is proportionately much longer and the apertural end is extended to form a long neck.

17. QUINQUELOCULINA BARAGWANATHI, sp. nov. (Pl. VIII., figs. 6*a-c*; Pl. XII., fig. 3).

Test a little longer than broad, of rather irregular form; periphery subacute; chambers distinct, only moderately inflated; sutures depressed; surface matte, frequently ornamented by short, obliquely curved costae (1 or 2 to a chamber) extending inward from the peripheral angle and sloping toward the apertural end of the chamber; aperture semi-circular, with an everted lip and a flat, semi-circular tooth which is placed in front of the aperture.

Length 0·6 mm., breadth, 0·4 mm., thickness, 0·25 mm.

This is also a common species on the south coast of Australia, and I have specimens from shallow water, near Noumea, New Caledonia. Chapman's record (1907, p. 124) of "*Miliolina*" *undosa* (Karrer) from Torquay, Victoria, probably refers to the same form, but the Recent records of Karrer's species usually relate to a form with a produced apertural neck and a plate-like, sometimes bifid, tooth in the aperture.

18. QUINQUELOCULINA COSTATA d'Orbigny (Refs., Parr, 1932, p. 8).

Examples are common.

19. SPIROLOCULINA ANTILLARUM d'Orbigny (Refs., Parr, 1932, p. 9).

One specimen. The Southern Australian examples of this species attain a greater development than those from the West Indies.

20. SPIROLOCULINA MILLETTI Wiesner.

*S. nitida* Brady (*non* d'Orbigny), 1884, p. 149, pl. 9, figs. 9, 10 Millett, 1898, J. R. M. S., p. 265, pl. 5, figs. 9–13.

*S. milletti* Wiesner, 1912, Archiv f Protistenkunde, 25, p. 207 Cushman, 1917, U.S. Nat. Mus., Bull. 71, Pt. 6, p. 33, pl. 5, fig. 4. Wiesner, 1923, Die Miliolideen der ostlichen Adria, p. 30, pl 4, figs. 7, 8.

Fine specimens similar to those figured by Brady are frequent. They are more regularly formed than those figured by Millett from the Malay Archipelago.

21. SPIROLOCULINA LIMBATA d'Orbigny (Refs., Cushman, 1929, p. 44).

Many large specimens.

22. SIGMOILINA AUSTRALIS (Parr).

*Quinqueloculina australis* Parr, 1932, p. 7, pl. 1, figs. 8*a-c*.

This species was described by the writer from 7 miles E. of Cape Pillar, Tasmania, 100fms., and recorded also from shore sand, Point Lonsdale, Victoria, and elsewhere. I am indebted to Mr. Arthur Earland, F.R.M.S., for drawing my attention to the fact that it should be referred to *Sigmoilina*.

23. TRILOCULINA TRIGONULA (Lamarck) (Refs., Cushman, 1929, p. 56).

Examples are common. They are of the large, strongly inflated form which occurs so frequently on the coasts of Victoria and South Australia.

24. Triloculina striatotrigonula Parker and Jones.

*T. striatotrigonula* Parker and Jones, 1865, Phil. Trans. Roy. Soc., 155, p. 438 (*nomen nudum*).

*Miliolina insignis* Brady, 1884, pl. 4, fig. 10 (*non* fig. 8).
*T. insignis* Parr, 1932, p. 11, pl. 1, fig. 19.

*T. striatotrigonula:* Parr, 1941, Mining and Geol. Journ., 2 (5), p. 305.

Small specimens. The reasons for the use of this name instead of *T. insignis* (Brady) are given in the last reference quoted.

25. Triloculina terquemiana (Brady) (Ref., Brady, 1884, p. 166).

There is one example of this striate form of *T. tricarinata*.

26. Triloculina oblonga (Montagu) (Refs., Parr, 1932, p. 10).

Examples are rather common. In addition to the narrow form figured by Williamson, there are some broader specimens and two of the biloculine type I have figured from Point Lonsdale, Victoria.

27. Triloculina circularis Bornemann, (Refs., Cushman, 1929, p. 58).

Typical specimens are very common.

28. Triloculina circularis Bornemann, var. *sublineata* (Brady).

(Refs., Brady, 1884, p. 169.)

Brady described this form from off the Admiralty Islands, on the north coast of New Guinea, 15-25 fms. As figured by him, it has no apertural tooth or plate, but the Victorian specimens have a fairly large, flat, semi-circular tooth in front of the aperture. There are also more compressed and the chambers are not so inflated. Possibly they represent a new species.

29. Triloculina labiosa d'Orbigny (Refs., Parr, 1932, p. 220). Common.

30. Triloculina labiosa d'Orbigny, var. *schauinslandi* (Rhumbler).

(Refs., Parr, 1932, p. 220.)

Examples are very common.

31. Triloculina bassensis, sp. nov. (Pl. VIII., figs 7 *a-c*).

Test longer than broad, triloculine, typically with a truncate periphery which in the final chamber is frequently keeled on each edge; chambers distinct; sutures slightly depressed; surface covered with very short, delicate ridges which give a matte effect; aperture subquadrate, longer than wide, with an everted lip and an elongate tooth which is thicker at the inner end.

Length, 0·75 mm., breadth, 0·6 mm., thickness, 0·37 mm.

In many respects, this species resembles *Quinqueloculina subpolygona,* but is triloculine and smaller than the latter. It may also be compared with *Triloculina irregularis* (d'Orbigny), as figured by Cushman (1932, U.S. Nat Mus., Bull. 161, Pt. 1, p. 54, pl. 12, figs. 2 *a-c*) from off Fiji, 40-50 fms. In this species, the test in transverse section is almost rectangular, but in *T. bassensis* it is roughly triangular, because, unlike the Fijian species, the outer truncate margin of the penultimate chamber is in a plane oblique to that of the final chamber.

32. Pyrgo denticulata (Brady) (Refs., Cushman, 1929, p. 69).

Several specimens.

33. Nevillina coronata (Millett) (Pl. VIII., figs. 8 *a, b*).

*Biloculina coronata* Millett, 1898, J.R.M.S., p. 263, pl. 6, figs. 6*a-c*.
*Nevillina coronata:* Sidebottom, 1905 Mem. Proc. Manchester Lit Phil. Soc., 49 (11), pp. 1-4, pl.

There are eight examples of what appears to be the biloculine or *Pyrgo* stage of this species. They attain a length of 0·9 mm. and closely resemble Millett's figures and Sidebottom's figures 5 and 6. I have similar specimens from off Masthead Island, in the Capricorn Group, off the coast of Queensland, 20 fms. The adult stage, in which the test is unilocular, has not been met with and has apparently been recorded only by Sidebottom, whose specimens were from off the Andaman Islands, 16 fms., and Sulu roadstead, 12 fms.

## Family SORITIDAE.

34. Peneroplis planatus (Fichtel and Moll).

*P. planatus:* Cushman, 1933, U.S. Nat. Mus., Bull. 161, Pt. 2, p. 61, pl. 19, figs. 1-3 (gives refs.).
*P. pertusus* Parr (*non Nautilus pertusus* Forskal), 1943, Malac. Soc. Sth. Aust. Publ. No. 3, p. 22.

Three worn examples. This was previously incorrectly recorded from Barwon Heads by the writer as *P. pertusus.*

## Family SPIRILLINIDAE.

35. Spirillina vivipara Ehrenberg (Refs., Cushman, 1931, p. 3).

Two specimens.

36. Spirillina inaequalis Brady (Refs., Brady, 1884, p. 631).

There are many examples of this well-known Indo-Pacific form.

37. Spirillina denticulogranulata Chapman (Refs., Chapman, 1907, p. 133).

This species was described from shore sand, Torquay, Victoria, and is here represented by seven examples. It is probably the same as Brady's *S. limbata*, var. *denticulata*, from off East Moncoeur Island, Bass Strait, 38 fms. Brady has figured only one side of his specimen and, in the writer's opinion, based on the examination of many specimens of *Spirillina* from Bass Strait, the figure represents the dorsal aspect of an asymmetrical form identical with Chapman's species.

38. Spirillina denticulogranulata Chapman, var. *pulchra*, var. nov. (Pl. VIII., figs. 9 *a-c*; Pl. IX., figs. 1 *a-c*).

Variety differing from the typical form of the species in the more numerous whorls and greater number of more delicate tooth-like processes on the dorsal side. Diameter, 0·45 mm.

This form is represented by several specimens. A typical example and what is probably a weakly developed specimen of the same variety are figured. It is intermediate between *S. denticulogranulata* and an undescribed species occurring in the Middle Miocene at Muddy Creek, Victoria, in which the tooth-like processes are absent.

39. Spirillina runiana Heron-Allen and Earland (Pl. IX., figs. 2 *a, b*, 3).

*Spirillina vivipara* Ehrenberg, var. *runiana* Heron-Allen and Earland, 1930, J.R.M.S., p. 179, pl. 4, figs. 51-53.

Four specimens. This form, which appears to be specifically distinct from *S. vivipara*, was described from off Plymouth, England, from a depth of about 30 fms.

## Family NODOSARIIDAE.

40. Lenticulina sp.

Several weak specimens of the *L. gibba* group.

41. Vaginulina vertebralis Parr (Refs., Parr, 1932, p. 221).

Three specimens similar to that described by the writer from shore sand, Torquay, Victoria.

42. Vaginulina bassensis, sp. nov. (Pl. XII., figs. 4 *a, b*).

Test elongate, tapering, somewhat lobulate on the ventral side, compressed in the early stages, later becoming almost circular in transverse section; chambers distinct, increasing in height comparatively quickly, sometimes showing traces of coiling in the

early stages but usually added obliquely at an angle of about 45 deg., or more, with the amount of inflation increasing gradually; sutures distinct, later ones depressed; wall smooth, translucent; aperture eccentric, on the dorsal side, radiate. Length up to 1·5 mm.

There are numerous specimens. This is a puzzling species in several respects. It is not sufficiently compressed to be a typical *Vaginulina* but is nearer this genus than any other. The smaller, less developed specimens resemble some of the open-coiled species of the "*Cristellaria*" *crepidula* group, while a few of the larger examples would be referred to *Dentalina inornata* if found alone. The large series of specimens shows, however, that only one species is present.

43. Dentalina inornata d'Orbigny.

*D. inornata* d'Orbigny, 1846, For. Foss. Vienne, p. 44, pl. 1, figs. 50, 51. Chapman and Parr, 1937, Aust. Ant. Exped. 1911-14. Sci. Repts. [C.], I. (2), p. 60.

One specimen. This species is better known as *D. communis* d'Orbigny. The reasons for the disuse of this name are given in the reference by Chapman and Parr, quoted above.

44. Dentalina mutsui Hada (Pl. XII., fig. 5).

*D. mutsui* Hada, 1931, Sci. Repts Tohuku Imp. Univ., Ser. 4, Biology, 6 (1), p 97, text-fig. 50.

I have referred to this species, which was described from Mutsu Bay, Japan, 15-25 fms., a form of *Dentalina* which is very common at Barwon Heads. Except that they attain a length of 2 mm. as against 3·65 mm. in the Japanese examples, the specimens agree with Hada's description and figure.

45. Dentalina guttifera d'Orbigny.

*D. guttifera* d'Orbigny, 1846, Foram. Foss. Vienne, p. 49, pl. 2, figs. 11-13.

*Nodosaria pyrula* Brady (*non* d'Orbigny), 1884, p. 497, pl. 62, figs. 10-12 (and later authors).

One broken specimen.

46. Nodosaria scalaris (Batsch) (Refs., Brady, 1884, p. 510).

Several examples.

47. Frondicularia compta Brady, var. *villosa* Heron-Allen and Earland (Pl. IX., fig. 4).

*F. archiaciana* Brady (*non* d'Orbigny), 1884, p. 520, pl. 114, fig. 12.

*F. compta* Brady, var. *villosa* Heron-Allen and Earland, 1924, J.R.M.S., p. 157, pl. 10, figs. 54-55.

Two specimens. This appears to be the only Recent record of this form other than those of Brady and of Heron-Allen and Earland from off Raine Island, 155 fms. The last-named authors also had it from the Miocene of Batesford, Victoria.

48. Lagena laevis (Montagu).

*Vermiculum laeve* Montagu, 1803, Testacea Britannica, p. 524.

*Lagena vulgaris* Williamson, 1858, Recent Foram. Gt. Britain, p. 3, pl. 1, figs. 5, 5*a*.

The specimens are not typical, resembling fig. 14 of Pl. 56 of the "Challenger" Report.

49. Lagena perlucida (Montagu) (Refs., Cushman, 1923, p. 46).

The specimens are finely costate on the basal end.

50. Lagena striata (d'Orbigny) (Refs., Cushman, 1923, p. 54).

Typical specimens of the original globular type.

51. Lagena sulcata (Walker and Jacob) (Refs., Cushman, 1923, p. 57).

Good examples are common.

52. Lagena acuticosta Reuss (Refs., Cushman, 1923, p. 5).

The specimens have more costae (18-20) than in the typical form of this species.

53. Lagena acuticosta Reuss, var. *ramulosa* Chapman (Refs., Parr, 1932, p. 11).

This Southern Australian form of *L. acuticosta* is common in most Victorian shore gatherings.

54. Lagena gracillima (Seguenza) (Refs., Cushman, 1923, p. 23).

The specimens are all spirally twisted, and may be merely a smooth form of *L. distoma-margaritifera.*

55. Lagena distoma-margaritifera Parker and Jones (Refs., Parr, 1932, p. 11).

This beautiful species is common.

56. Lagena distoma-margaritifera, var. *victoriensis,* nov. (Pl. XII., fig. 6).

Test elongate, usually spirally twisted, fusiform with the aboral end pointed and the apertural end extended into a long neck which terminates in a phialine lip; surface ornamented with from eight to ten strong costae.

Length up to 1·5 mm.

This form is common in Victorian shore sands. Its shape is similar to that of *L. distoma-margaritifera*, with which it is always associated, and it appears to be only a costate modification of that species. The twisted and costate test distinguish it from *L. distoma* Parker and Jones.

57. Fissurina lucida (Williamson) (Refs., Cushman, 1923, p. 33).

One specimen.

58. Fissurina biancae Seguenza.

*F. laevigata* Reuss, 1849 (*non Oolina laevigata* d'Orbigny), Denkschr. Akad. Wiss. Wien, 1, p. 366, pl. 46, fig. 1.

*F. biancae* Seguenza, 1862, Foram. Monot. Marne Miocen. Distretto Messina, p. 57, pl. 1, figs. 48-50.

*Lagena biancae* Heron-Allen and Earland, 1932, Discovery Repts., 4, p 372, pl 10, figs. 35-39.

One good example. This species has frequently been recorded under the name of *Lagena laevigata* (Reuss) which is preoccupied by an earlier species described by d'Orbigny.

59. Fissurina subquadrata, sp. nov. (Pl. IX., figs. 5 *a, b*).

Test much compressed, subquadrate in outline, periphery bluntly carinate; surface with two shallow grooves on each face, parallel to the outside margin and almost meeting at the base; aperture fissurine, extending almost the full width of the test, and opening into a centrally placed entosolenian tube.

Length, 0·4 mm.

Two specimens. *F. quadrata* (Williamson), which this species resembles in many respects, has the apertural end produced into a short neck and the faces of the test are not grooved.

60. Fissurina lacunata (Burrows and Holland).

*Lagena castrensis* Brady (*non* Schwager),1884, p. 485, pl. 60, figs. 1, 2

*L. lacunata* Burrows and Holland, in Jones, 1895, Pal. Soc., vol. for 1895, p. 205, pl. 7, figs. 12 *a, b*.

There are many specimens similar to Brady's fig. 1, which was from Bass Strait. In *F. castrensis*, the faces of the test are beaded and not pitted as in *F. lacunata*.

61. Fissurina contusa, sp. nov. (Pl. IX., fig. 6).

*Lagena castrensis* (?)Brady (*non* Schwager), 1884, pl. 60, fig. 3.

Test compressed, the central body portion nearly circular, apertural end slightly extended, periphery with a moderately sharp keel which surrounds the test and on either side of which is a secondary lateral keel slightly raised above the general surface; wall on the body portion ornamented with a number of small pits which vary in size; aperture fissurine, elongate, and opening into an entosolenian tube which extends about half way down one face of the test and is recurved at its inner end.

Length, 0·35 mm.

This appears to be the same form as that figured by Brady from off Raine Island, Torres Strait, 155 fms., under the name of *Lagena castrensis.*' It is common in Bass Strait, and, while usually occurring with *F. lacunata*, differs from this species in its apertural characters and in the weaker pitting of the surface.

62. FISSURINA ORBIGNYANA (Seguenza), variety (Pl. IX., fig. 7).

There are ten examples of a form of *F. orbignyana*, which in front view is pyriform, with the apertural end only slightly extended and the central portion of the test on each side bearing a white, horse-shoe shaped marking, the rounded end of which is directed towards the base of the test.

63. FISSURINA LAGENOIDES (Williamson) (Refs., Cushman, 1923, p. 30).

One fairly typical example.

64. ENTOSOLENIA GLOBOSA (Montagu) (Refs., Cushman, 1923, p. 20).

Numerous specimens They are nearly all faintly hispid, but one has the surface thickenings developed to such an extent that it could be referred to *E. ampulla-distoma* (Rymer Jones)

65. ENTOSOLENIA SQUAMOSA (Montagu) (Refs., Cushman, 1923, p. 51).

One very typical specimen.

## Family POLYMORPHINIDAE.

66. GUTTULINA YABEI Cushman and Ozawa (Refs., Parr and Collins, 1937, p. 192).

Two small examples.

67. GUTTULINA REGINA (Brady, Parker, and Jones) (Refs., Parr and Collins, 1937, p. 193).

Many specimens. A series of abnormal examples of this species from Barwon Heads has been figured by Parr and Collins.

68. GUTTULINA LACTEA (Walker and Jacob) (Refs., Parr and Collins, 1937, p. 195).

Rare, but typical.

69. GUTTULINA SEGUENZANA (Brady) (Refs., Parr and Collins, 1937, p. 196).

Rare. This is already known from the Victorian coast

70. GLOBULINA GIBBA d'Orbigny, var. *globosa* (Münster) (Refs., Parr and Collins, 1937, p. 199).

Common. There are many fistulose specimens.

71. POLYMORPHINA HOWCHINI Cushman and Ozawa (Refs., Parr and Collins, 1937, p. 202).

Several examples

72. SIGMOMORPHINA WILLIAMSONI (Terquem) (Refs, Parr and Collins, 1937, p. 205).

Two specimens This has been previously figured by the writer from Hobson's Bay.

73. SIGMOIDELLA ELEGANTISSIMA (Parker and Jones) (Refs., Parr and Collins, 1937, p. 206)

Six small examples.

## Family HETEROHELICIDAE.

74. BOLIVINELLA FOLIUM (Parker and Jones) (Refs, Parr, 1932, p. 223).

Several worn examples

## Family BULIMINIDAE.

75. BULIMINELLA ELEGANTISSIMA (d'Orbigny) (Refs., Brady, 1884, p. 402).

Two good examples.

76. BULIMINOIDES WILLIAMSONIANUS (Brady) (Refs., Brady, 1884, p. 408).

Three specimens. This species ranges from Torres Strait down the east coast of Australia and westward to South Australian waters. It is most common in shallow water.

77. BULIMINA MARGINATA d'Orbigny (Refs., Brady, 1884, p. 405).

Three specimens. The Australian examples are usually proportionately shorter than those from Europe

78. VIRGULINA SCHREIBERSIANA Czjzek.

*V. schreibersiana:* Cushman, 1937, Cushman Lab. Spl. Publ No 9, p. 13, pl. 2, figs. 11-20 (gives refs.).

Several large examples. This species also occurs in Westernport Bay, Victoria.

79. BOLIVINA COMPACTA Sidebottom (Pl. IX., fig. 8).

*B. compacta:* Cushman, 1937, Cushman Lab. Spl. Publ. No. 9, p. 135, pl. 17, figs. 22-24 (gives refs.).

Two specimens. Cushman records this species from a number of shallow water dredgings in the tropical Pacific.

80. BOLIVINA PSEUDOPLICATA Heron-Allen and Earland (Pl. IX., fig. 9).

*B. pseudoplicata:* Cushman, 1937, Cushman Lab. Spl. Publ No 9, p. 166, pl. 19, figs. 12-20 (gives refs.)

Typical examples are common.

81. RECTOBOLIVINA DIGITATA, sp. nov. (Pl. IX., fig. 10).

Test elongate, compressed, straight or slightly curved, with the margins lobulate, biserial portion with a slight median depression on each of the broad faces, uniserial portion also depressed in the upper part of the centre of each chamber, sutures distinct, often a little depressed; chambers numbering 6 to 8 in the biserial portion, with 5 or 6 in the uniserial portion, wall calcareous, smooth, fairly coarsely perforate except along the median line; aperture elliptical, with a rounded rim Length, 0·6 mm.; breadth, 0·15 mm.

There are two examples from Barwon Heads and I have a number from the Post-Tertiary of Victorian Mines Department Bore No. 5, Parish of Wannaeue, near Rosebud, 177-187 feet. This species differs from the well-known Indo-Pacific Recent species, *R. bifrons* (Brady), in its more irregular build, greater number of biserial chambers, less compressed uniserial portion, and more coarsely perforated test.

82. REUSSELLA ARMATA (Parr) (Refs., Parr. 1932, p. 224).

Three examples. The only previous record of this species is from shore sand, Hardwicke Bay, South Australia.

83. CHRYSALIDINELLA DIMORPHA (Brady) (Refs., Brady, 1884, p. 388).

One specimen. It is proportionately narrower and more heavily built than are the tropical examples of this species.

84. UVIGERINA sp. cf. PIGMEA d'Orbigny.

There are six specimens of the form I have recorded (1939, Mining Geol. Journ., 1 (4), p. 68, pl., fig. 14) from the Lower Pliocene of Gippsland. It is probably not d'Orbigny's *U. pigmea,* but this cannot at present be determined with certainty.

85. SIPHOGENERINA RAPHANUS (Parker and Jones) (Refs., Parr, 1932, p. 225).

Examples are frequent and typical.

86. ANGULOGERINA ANGULOSA (Williamson).

*Uvigerina angulosa* Williamson, 1858, Recent Foram. Gt. Britain, p. 67, pl. 5, fig. 140.

There are three specimens similar to examples of the typical British form of this species from Dog's Bay, Ireland.

## Family CASSIDULINIDAE.

87. CASSIDULINA LAEVIGATA d'Orbigny (Refs., Brady, 1884, p. 428).

One small specimen.

88. CASSIDULINA SUBGLOBOSA Brady (Refs., Cushman, 1922, p. 127).

Three small specimens.

89. EHRENBERGINA PACIFICA Cushman.

*E. pacifica* Cushman, 1927, Proc. U.S. Nat. Mus, 70, Art. 16, p. 5, pl. 2, figs. 2 *a-c*.

One small example. This species is common off the coast of New South Wales.

## Family DELOSINIDAE.

90. DELOSINA COMPLANATA Earland (Pl. X., figs. 1, 2).

*Polymorphina complexa* Sidebottom, 1907, Mem. Proc. Manchester Lit. Phil. Soc, 51 (9), p. 16, pl. 4, figs 4, 8, (?) 9. Heron-Allen and Earland, 1916, J.R M.S., p. 48, pl. 8, figs. 5-7.

*Delosina complanata* Earland, 1934, Discovery Reports, 10, p. 128.

One of the most interesting occurrences in the shore gatherings from Barwon Heads is that of numerous examples of the genus *Delosina*. The specimens are exceptionally well developed and are very variable in form. Generally, however, the chambers are almost biserially opposed on a plan similar to the chambers in the genus *Sigmomorphina*. The plan of growth is best shown in the large compressed specimens, one of which is represented by fig. 2 of Pl. X. While Earland has described the chambers as at first triserial rapidly becoming biserial and opposed, the chambers in the Victorian examples appear to be biserial from the beginning but in the early stages are separated by a greater angle than the

later chambers, giving a twisted effect to the test when viewed from the base. The Wiesner canals with the needle-stitch-like openings through which they communicate with the exterior of the test are recognisable in all specimens. There are usually a number of pits on the surface of the end of that last-formed chamber, but there is no general aperture. In one specimen sectioned, the first two chambers showed a comparatively large, rounded, terminal opening; This may, however, be due to the resorption of the end of the chamber.

According to Earland, *D. complanata* always occurs in the Mediterranean with *D. complexa* and with about equal rarity. He also records the species from South Cornwall and from off Cape Horn. This gives it a very wide distribution. In addition to the Barwon Heads examples, I have met with the species in a number of dredgings from Bass Strait, and in shore sands from the north coast of Tasmania.

The Victorian specimens are usually half as large again as those figured by Sidebottom from the Eastern Mediterranean, attaining a length of 0·75 mm.

## Family ROTALIIDAE.

91. Patellina corrugata Williamson.

*P. corrugata* Williamson, 1858, Recent Foram, Gt. Britain, p. 46, pl. 3, figs. 86-89. Parr and Collins, 1930, Proc. Roy. Soc Vic, n s 43 (1), p 90, pl. 4, figs. 1-5.

Two examples.

92. Annulopatellina annularis (Parker and Jones) (Refs., Parr, 1932, p. 225).

Many specimens.

93. Patellinella inconspicua (Brady).

*P. inconspicua* Parr and Collins, 1930, Proc Roy. Soc. Vic, n.s. 43 (1), p 92, pl. 4, fig. 7 (gives refs ).

Typical examples occur frequently.

94. Discorbis dimidiatus (Jones and Parker) (Refs., Parr, 1932, p. 227).

Common. This is the most abundant species of *Discorbis* on the southern coast of Australia.

95. Discorbis globularis (d'Orbigny) (Refs., Cushman, 1931, p. 22).

One example, more depressed than usual, and with a subcarinate margin to the test.

96. DISCORBIS GLOBULARIS (d'Orbigny), var. *anglica* Cushman (Pl. IX., figs. 11 *a-c*).

*D. globularis*, var. *anglica* Cushman, 1931, p 23, pl 4, figs. 10*a-c*.
*D. irregularis* Parr (*non Discorbina irregularis* Rhumbler), 1943, Malac. Soc. Sth. Aust. Publ. No. 3, p. 16.

Many specimens. I previously recorded this form as *D. irregularis* (Rhumbler), which in most respects is resembles, but the specimens do not have the several apertures found on the peripheral margin of the later chambers in Rhumbler's species from the tropical Pacific.

97. DISCORBIS AUSTRALIS Parr (Refs., Parr, 1932, p. 227).

This species was described from San Remo, Victoria. It is common at Barwon Heads.

98. DISCORBIS PATELLIFORMIS (Brady) (Refs., Brady, 1884, p. 647).

This well-known Indo-Pacific species is represented by a few small examples.

99. DISCORBIS AUSTRALENSIS Heron-Allen and Earland.

*Discorbina pileolus* Brady (*non Valvulina pileolus* d'Orbigny), 1884, p. 649, pl. 89, figs. 2-4 (and later authors).
*Discorbis australensis* Heron-Allen and Earland, 1932, Discovery Repts, 4, p. 416. Parr. 1939, Mining and Geol. Journ., 1 (4), p. 68.

This species is well known from the east coast of Australia under the name of *D. pileolus*. At Barwon Heads it occurs frequently.

100 DISCORBIS OPERCULARIS (d'Orbigny) (Refs., Brady, 1884, p. 650).

Rare.

101. DISCORBIS KENNEDYI, sp. nov. (Pl. IX., figs. 12 *a, b*, 13, 14 *a, b*).

Test depressed conical, ventral side slightly concave, periphery subacute; chambers not distinct, 4 to 5 in the last-formed whorl, regularly increasing in size, overlapping on the ventral side; spiral suture depressed in the later part of the test, chamber sutures directed backwards and slightly curved on the dorsal side, usually indistinct, almost radial and somewhat depressed on the ventral side; wall irregularly thickened so as to give an arenaceous appearance to the surface, finely perforate, the periphery limbate; aperture ventral, at the base of the last-formed chamber, opening into the umbilical depression; colour white to pale-brown.

Diameter, 0·4 mm.

There are eleven examples of this species, which appears to be a local form, as I have not met it elsewhere on the Australian coast or in material from other parts of the world. The under side of the last-formed chamber is easily broken, as every specimen is incomplete in this respect. The rough surface texture and the usually brownish colour give an appearance like that of some species of *Trochammina*. I have pleasure in associating the name of Mr. Arthur Kennedy, of the Victorian Department of Mines, with this species.

102. DISCORBIS WILLIAMSONI Chapman and Parr (Pl. X., figs. 3 *a*, *b*).

*D. williamsoni* Chapman and Parr M.S.: Parr, 1932, p. 226, pl 21, fig. 25 (gives earlier refs.). Chapman and Parr, 1937, Aust. Antarctic Exped. 1911-14, Sci. Repts [C.], 1 (2), p. 105, pl. 8, fig 23.

Many examples.

103. DISCORBIS PULVINATUS (Brady) (Ref., Brady, 1884, p. 650).

Three typical specimens. This species is common in shallow water on the south coast of Australia.

104. DISCORBIS BERTHELOTI (d'Orbigny) (Refs, Cushman, 1931, p. 16).

Two small specimens.

105. DISCORBIS RARESCENS (Brady) (Pl. X., figs. 5 *a-c*) (Ref., Brady, 1884, p. 651).

Three examples. Brady's specimens were from off Raine Island, Torres Strait, 155 fms., and off the Philippines, 95 fms.

106. DISCORBIS GROSSEPUNCTATUS, sp. nov. (Pl. X., figs. 4 *a-c*).

Test plano-convex, oval, peripheral margin limbate, bluntly keeled; chambers, usually four in the final whorl the last much larger than the others; sutures slightly depressed, distinct, almost radial on the dorsal side, limbate and strongly recurved on the ventral side; wall very coarsely perforate on the dorsal side, smooth and finely perforate ventrally, with a deposit of shell material in the centre of the test; aperture not clearly visible but possibly a very low slit extending from near the periphery along the base of the last-formed chamber to near the centre of the test. The curvature of the sutures on the flat side of the test suggests that this species would be better referred to *Cibicides*.

Greater diameter, 0·65 mm.; lesser diameter, 0·4 mm.

Two specimens. I have other examples from the Middle Miocene of Mines Department bore No. 1, Parish of Yulecart, near Hamilton, 80-85 ft. This is not a typical *Discorbis*, but resembles *D. rarescens* and some of the forms referred by authors to *D. bertheloti*, in which the earlier whorls are visible only on the ventral side. The aperture cannot be determined with certainty, and it is possible that it is absent. A similar difficulty is frequently experienced in detecting the ventral aperture in species of *Discorbinella*.

107. HERONALLENIA LINGULATA (Burrows and Holland).

*H. lingulata:* Chapman, Parr, and Collins, 1934, Journ. Linn. Soc. (London)—Zool., 38, p 564, pl 8, figs. 11*a-c* (gives refs.).

Three typical examples.

108. HERONALLENIA TRANSLUCENS, sp. nov. (Pl IX., figs. 15, 16).

Test small, suboval in outline, compressed, dorsal side more convex than the ventral which is depressed in the median portion, peripheral margin subacute and slightly keeled; chambers few, arranged in one and a half whorls, with six chambers in the outside whorl; sutures distinct, limbate, flush, recurved on the dorsal side and nearly radial on the ventral; wall smooth, finely perforate, usually translucent; aperture ventral, an elongate opening extending from the umbilical area towards the front of the last-formed chamber. Length, up to 0·35 mm.

This species is represented by two examples and it also occurs in dredgings from Bass Strait. It differs from described species of *Heronallenia* in its well-inflated test, flush dorsal sutures, and the absence of any thickening of the shell wall on the upper surface.

109. DISCORBINELLA BICONCAVA (Jones and Parker).

*Discorbina biconcava* Jones and Parker, in Carpenter, 1862, Intro. Study Foram., p 201, text-fig. 32 G. Brady, 1884, p. 653, pl. 91, fig. 2 (*non* 3).

*Planulinoides biconcavus*· Parr, 1941, Mining and Geol. Journ, 2 (5), p. 305, text-fig. (after Brady).

There are many examples of this typically Southern Australian species. Since erecting the genus *Planulinoides* for its reception, I have recognized the presence in some specimens of the normal ventral discorbine aperture in addition to that on the periphery. *Planulinoides* should therefore be suppressed and the species referred to *Discorbinella.*

110. DISCORBINELLA PLANOCONCAVA (Chapman, Parr, and Collins) (Pl. XI., figs. 1, 2).

*Planulina biconcava* (Jones and Parker), var. *planoconcava* Chapman, Parr, and Collins MS., in Parr, 1932, p. 232, pl. 22, figs 34 *a-c*

*Discorbis planoconcava* Chapman, Parr, and Collins, 1934, Journ. Linn. Soc. (London)—Zool, 38, p. 561, pl. 11, figs. 40 *a-c*.

There are sixteen examples of this species, which was described from the Middle Miocene of Victoria and also recorded as a Recent form from shore sand, Point Lonsdale, Victoria.

111. Discorbinella disparilis (Heron-Allen and Earland) (Pl. XI., figs. 3 *a-c*) (Refs., Parr, 1932, p. 230).

There are 22 specimens Like the preceding species, this is a typical *Discorbinella,* with two apertures, one peripheral and the other ventral. It was originally described from off New Zealand, 100 fms., and later recorded by the writer from shore sand, Victoria, and Hardwicke Bay, South Australia.

112. Discorbinella involuta (Sidebottom).

*Discorbina involuta* Sidebottom, 1918, J R.M S., p. 255, pl. 6, figs 15-17.

Four specimens. Sidebottom's record was from off the coast of New South Wales, 465 fms. The species is widely distributed on the east coast of Australia and in Bass Strait.

113. Valvulineria collinsi (Parr).

*Discorbis collinsi* Parr, 1932, p. 230, pl 22, figs. 33 *a-c*.

Seven specimens. The original record of this species was from shore sand, Port Fairy, Victoria.

114. Tretomphalus concinnus (Brady) (Pl. XI., figs. 4, 5).

*T. concinnus:* Cushman, 1934, Contrbns. Cushman Lab. Foram Research, 10 (4), p. 96, pl 11, figs. 8, 9; pl. 12, figs. 13-15 (gives Brady's ref.).

Examples were very common in one gathering.

115. Tretomphalus planus Cushman.

*T. planus* Cushman, 1934. Contrbns. Cushman Lab. Foram Research, 10 (4), p. 94, pl. 11, figs. 11*a-c;* pl. 12, figs. 18-22.

Like the preceding, this species was very common in one gathering. While the majority of the specimens have the depressed, cushion-like shape represented by Cushman's fig. 11 *b*, many are subglobular because of the deeper, more rounded balloon chamber. The number of *Cymbaloporetta*-like chambers underlying the balloon chamber is usually four, but is sometimes five. Cushman described this species from off Samoa, 7 fms., and he gives other records from the tropical Pacific. The genus *Tretomphalus* is, from published records, typically of tropical habitat, and its occurrence in such numbers at Barwon Heads is therefore unusual. Occasional examples of *T. concinnus* occur in Victorian shore sands and in dredgings from Bass Strait, but this is the only occasion on which I have met with *T. planus* in this area. Mr. Arthur Earland, F.R.M.S. (1902, Journ. Quekett Micr. Club, [2], 8, (51), pp. 309-322) has recorded a remarkable occurrence of *Tretomphalus* at Corny Point, on Hardwicke Bay, Spencer Gulf, South Australia. From his description, it appears that the species he had was *T. concinnus.*

116. Eponides concentricus (Parker and Jones) (Pl. XI., figs. 6 *a*, *b*) (Refs., Cushman 1931, p. 43)

Frequent. The characters of this species suggest that it might be referred to *Mississippina* rather than to *Eponides*.

117. Streblus beccarii (Linné) (Refs., Cushman, 1931, p. 58).

Many specimens. They do not attain the development of the species as it occurs in the Adriatic Sea, but are exactly similar to British examples Mr Arthur Earland has sent me from Tents Muir, Fifeshire, Scotland. The usual number of chambers in the outside whorl is ten.

118. Streblus pauperatus Parr.

*Rotalia perlucida* Parr (*non* Heron-Allen and Earland), 1932, p. 211, pl. 22, figs. 35*a*-*c*.

*Streblus pauperatus* Parr, 1941, Mining and Geol Journ., 2 (5), p 305.

Two examples. The previous record of this species was from shore sand, Hardwicke Bay, South Australia.

119. Notorotalia clathrata (Brady).

*Rotalia clathrata* Brady, 1884, p. 709, pl 107, fig. 8 (*non* 9).

*Notorotalia clathrata:* Finlay, 1939, Trans. Roy. Soc. N.Z., 68, p. 518 (note under *N. zelandica* Finlay).

Several examples. This is a common Bass Strait species.

120 Cancris sp. (Pl. XI., figs. 7 *a*-*c*).

The figures represent what appears to be a species of *Cancris*. The test is roughly ear-shaped in outline, with a lobulated periphery. The chambers, which are inflated, increase rapidly in size as added and the sutures are well depressed. The greater part of the face of the last-formed chamber is occupied by a clear, apparently imperforate, area The base of this is extended as a lip under which the aperture opens into the umbilical cavity. While the species is probably new, there are too few specimens available to enable its characters to be fully determined.

121. Baggina philippinensis (Cushman).

*Cancris philippinensis:* Parr, 1939, Mining and Geol. Journ., 1 (4), p. 69, pl., figs. 18*a*-*c* (gives refs.).

Five small specimens. This species occurs frequently in dredgings off the coast of New South Wales, at depths of about 100 fms., and is common in the Pliocene of Victoria.

122. Anomalina nonionoides Parr (Refs., Parr, 1932, p. 231).

There are ten specimens. This species was described by the writer from shore sand, Narrabeen, New South Wales, and also recorded from shore sand, Torquay, Victoria.

123. Cibicides lobatulus (Walker and Jacob) (Refs., Cushman, 1931, p. 118).

Examples are common. In addition to the usual form of this species, there are many specimens showing a *Dyocibicides* plan of growth and three with the chambers arranged as in *Rectocibicides*. Some English examples of *C. lobatulus* also develop a biserial habit of growth, although I have not seen any with as many biserial chambers as those from Barwon Heads.

124. Planorbulina mediterranensis d'Orbigny (Refs., Cushman, 1931, p. 129).

There are numerous examples of the very well-developed form so common in Victorian shore sands. This is possibly not the same as d'Orbigny's species.

125. Acervulina inhaerens Schultze (Refs., Cushman, 1931, p. 134).

Several specimens.

126. Gypsina vesicularis (Parker and Jones) (Refs., Cushman, 1931, p. 135).

Six specimens. They are almost hemispherical in shape, and are very neatly built.

127. Miniacina mineacea (Pallas).

*Polytrema mineaceum:* Heron-Allen and Earland, 1922, Brit. Antarctic ("Terra Nova") Expedn., 1910, Nat. Hist. Rept., Zool., 6 (2), p. 221, pl. 8, figs. 1-31.

Recognizable fragments only. This species is common on the coast of New South Wales.

## Family CHILOSTOMELLIDAE.

128. Sphaeroidina bulloides d'Orbigny (Refs., Cushman, 1924, p. 36).

Small specimens.

## Family ORBULINIDAE.

129. GLOBIGERINA BULLOIDES d'Orbigny.

*G. bulloides* d'Orbigny, 1826, Ann. Sci. Nat., 7, p. 277, No. 1; Modèles Nos. 17, 76. Cushman, 1941, Contrbns. Cushman Lab., 17 (2), p. 38, pl. 10, figs. 1-13.

Frequent, but small.

130. GLOBIGERINA INFLATA d'Orbigny (Refs., Cushman, 1924, p. 12).

Frequent.

131. GLOBIGERINOIDES RUBER (d'Orbigny) (Refs., Cushman, 1924, p. 15).

Seven specimens. Like all other Southern Australian examples of this species I have seen, they are colourless.

132. ORBULINA UNIVERSA d'Orbigny (Refs., Cushman, 1924, p. 28).

Several examples.

133. GLOBOROTALIA HIRSUTA (d'Orbigny) (Refs, Cushman, 1931, p. 99).

This pelagic species is represented by a single example.

124. GLOBOROTALIA TRUNCATULINOIDES (d'Orbigny) (Refs., Cushman, 1931, p. 97).

Typical examples.

## Family NONIONIDAE.

135. NONION DEPRESSULUS (Walker and Jacob).

*N. depressulum:* Cushman, 1939, U.S. Geol. Survey Prof. Paper 191, p 20, pl. 5, figs. 22-25 (gives refs.).

Rare. The specimens are similar to some I have from Bognor, England.

136. NONION SCAPHA (Fichtel and Moll).

*N. scapha:* Cushman, 1939, U.S. Geol. Surv. Prof. Paper 191, p. 20, pl. 5, figs. 18-21 (gives refs.).

Four examples of the typical form of this species. The number of chambers in the last-formed coil varies from eleven to twelve.

137. Elphidium sp. cf. simplex Cushman (Pl. XI., fig. 8).

Cf. *E. simplex* Cushman, 1939, U.S. Geol. Survey Prof. Paper 191, p. 62, pl. 17, fig. 10 (gives refs.)

There are several examples of a species of *Elphidium* which may be a temperate water form of *E. simplex*, described by Cushman from off Tonga, in the South Pacific. The retral processes are better defined than in Cushman's figure, and there is no boss in the umbilical region, which is merely granulated.

138. Elphidium sp. aff. articulatum (d'Orbigny) (Pl. XI., figs. 9 *a, b*).

Cf. *E. articulatum* Cushman, 1939, U.S Geol. Survey Prof. Paper 191, p. 53, pl. 14, figs. 18, 19.

The specimens agree with *E. articulatum* in the shape and number of chambers to a whorl (10), but the test is narrower in apertural view in the earlier portion and the umbilical region is superficially thickened. *E. articulatum* was described from the vicinity of the Falkland Islands.

139. Elphidium advenum (Cushman)

*E. advenum* (Cushman). Cushman, 1939, U.S. Geol. Survey Prof. Paper 191, p. 60, pl. 16, figs 31-35 (gives refs.).

Several examples. They resemble fig. 1 of Pl. 110 of the "Challenger" Report.

140. Elphidium argenteum, sp. nov. (Pl. XII. figs. 7 *a, b.*).

Test comparatively large, compressed, periphery subacute with a small blunt keel, margin slightly lobulated, sides nearly parallel in front view, umbilical regions moderately depressed with the surface thickened; chambers numerous, 15–17 in the last-formed whorl, slightly inflated; sutures recurved, obscured by the retral processes, which are rod-like and fairly conspicuous, averaging about 12 in number; surface closely and finely beaded, giving a silvery appearance to the test; aperture a series of rounded openings situated a short distance above the base of the apertural face. Diameter, up to 1 mm.; thickness, to 0·35 mm.

This is the commonest species of *Elphidium* in Victorian shore sands. It is apparently the same species as that recorded by Chapman (1907, p. 141) as *Polystomella striatopunctata* (Fichtel and Moll) from a number of Victorian littoral gatherings, but Fichtel and Moll's figures show that their species is an unrelated form. Like most species of *Elphidium*, *E. argenteum* appears to be restricted in its occurrence. *E. advenum*, var. *margaritacea* Cushman, from off Rhode Island, U.S.A., shows some resemblance to it but has fewer chambers and retral processes.

141. ELPHIDIUM MACELLUM (Fichtel and Moll).

*E. macellum* (Fichtel and Moll): Cushman, 1939, U S Geol. Surv. Prof. Paper 191, p. 51, pl. 14, figs 1-3, pl. 15, figs. 9, 10

Several specimens.

142. ELPHIDIUM IMPERATRIX (Brady) (Refs., Brady, 1884, p. 738).

Three immature examples. This species appears to be confined to an area extending along the east coast of Australia from near Sydney to Tasmania.

## Explanation of Plates.

### PLATE VIII.

FIGS 1, 2.—*Ammodiscus mestayeri* Cushman × 40.

FIG 3.—*Webbinella bassensis*, sp nov. Holotype. × 40.

FIG. 4.—*Trochammina inflata* (Montagu). × 40.

FIG. 5.—*Eggerella* sp. × 65

FIG 6.—*Quinqueloculina baragwanathi*, sp. nov. Holotype. *a, b*, opposite sides. × 40; *c*, apertural view, × 65.

FIG. 7.—*Triloculina bassensis*, sp. nov Holotype. *a, b*, opposite sides. × 40, *c*, apertural view. × 65

FIG. 8.—*Nevillina coronata* (Millett) Biloculine specimen. *a*, front view. × 40; *b*, side view. × 35.

FIG. 9.—*Spirillina denticulogranulata* Chapman, var *pulchra* nov. *a, b*, opposite sides; *c*, peripheral view. × 65

### PLATE IX.

FIG. 1.—*Spirillina denticulogranulata* Chapman. var. *pulchra*, nov. Holotype of variety. *a, b*, opposite sides × 55; *c*, peripheral view. × 65.

FIG. 2.—*Spirillina runiana* Heron-Allen and Earland. *a*, dorsal view; *b*, peripheral view. × 65.

FIG. 3.—*Spirillina runiana* Heron-Allen and Earland. Ventral aspect. × 65.

FIG. 4.—*Frondicularia compta* Brady, var. *villosa* Heron-Allen and Earland. × 40

FIG 5.—*Fissurina subquadrata*, sp. nov. Holotype *a*, front view; *b*, apertual view. × 65

FIG. 6.—*Fissurina contusa*, sp. nov. Holotype Front view. × 65.

FIG. 7.—*Fissurina orbignyana* Seguenza, var. Front view. × 65.

FIG. 8.—*Bolivina compacta* Sidebottom. × 65.

FIG. 9.—*Bolivina pseudoplicata* Heron-Allen and Earland. × 65.

FIG. 10.—*Rectobolivina digitata*, sp. nov. Holotype. × 65.

FIG 11.—*Discorbis globularis* (d'Orbigny), var. *anglica* Cushman. *a*, dorsal view; *b*, ventral view; *c*, peripheral view. × 65.

FIG 12.—*Discorbis kennedyi*, sp. nov. Holotype. *a*, dorsal view; *b*, peripheral view. × 65.

FIG. 13.—*Discorbis kennedyi*, sp nov. Ventral view of another example. × 65.

FIG 14.—*Discorbis kennedyi*, sp nov. Another example, *a*, ventral view; *b*, peripheral view. × 65.

FIG. 15, 16.—*Heronallenia translucens*, sp. nov. Fig. 15 Holotype. Dorsal view. Fig. 16 Ventral view of another example. Both × 65.

## Plate X.

Figs. 1, 2.—*Delosina complanata* Earland Fig. 1, *a*, *b*, opposite sides; *c*, edge view. Fig 2, *a*, *b*, opposite sides. All × 65.

Fig. 3—*Discorbis williamsoni* Chapman and Parr, *a*, dorsal view; *b*, ventral view. × 65.

Fig. 4.—*Discorbis grossepunctatus*, sp nov. Holotype *a*, dorsal view; *b*, ventral view, *c*, edge view. × 65

Fig. 5—*Discorbis rarescens* (Brady), *a*, dorsal view; *b*, ventral view; *c*, edge view. × 65.

## Plate XI.

Figs 1, 2—*Discorbinella planoconcava* (Chapman, Parr and Collins). Fig 1, *a*, *b*, dorsal and ventral views. Fig 2, edge view of another specimen showing peripheral aperture. All × 65.

Fig. 3—*Discorbinella disparilis* (Heron-Allen and Earland), *a* dorsal view, *b*. ventral view, *c* edge view × 65.

Figs 4, 5—*Tretomphalus concinnus* (Brady). Fig. 4, side view. Fig 5, dorsal view of another specimen. Both × 65

Fig. 6.—*Eponides concentricus* (Parker and Jones). *a*, dorsal view; *b*, ventral view. × 65.

Fig 7—*Cancris* sp *a*, dorsal view, *b*, ventral view. × 40, *c*, edge view. × 65.

Fig. 8—*Elphidium* sp. cf. *simplex* Cushman × 65.

Fig 9—*Elphidium* sp. aff. *articulatum* (d'Orbigny). *a*, side view, *b*, apertural view. × 65

## Plate XII.

Fig. 1.—*Planispirina* (?) *bucculenta* (Brady) *a*, side view, *b*, apertural view. × 43.

Fig. 2—*Quinqueloculina subpolygona*, sp nov. Holotype *a*, *b*, opposite sides; *c*, apertural view. × 43

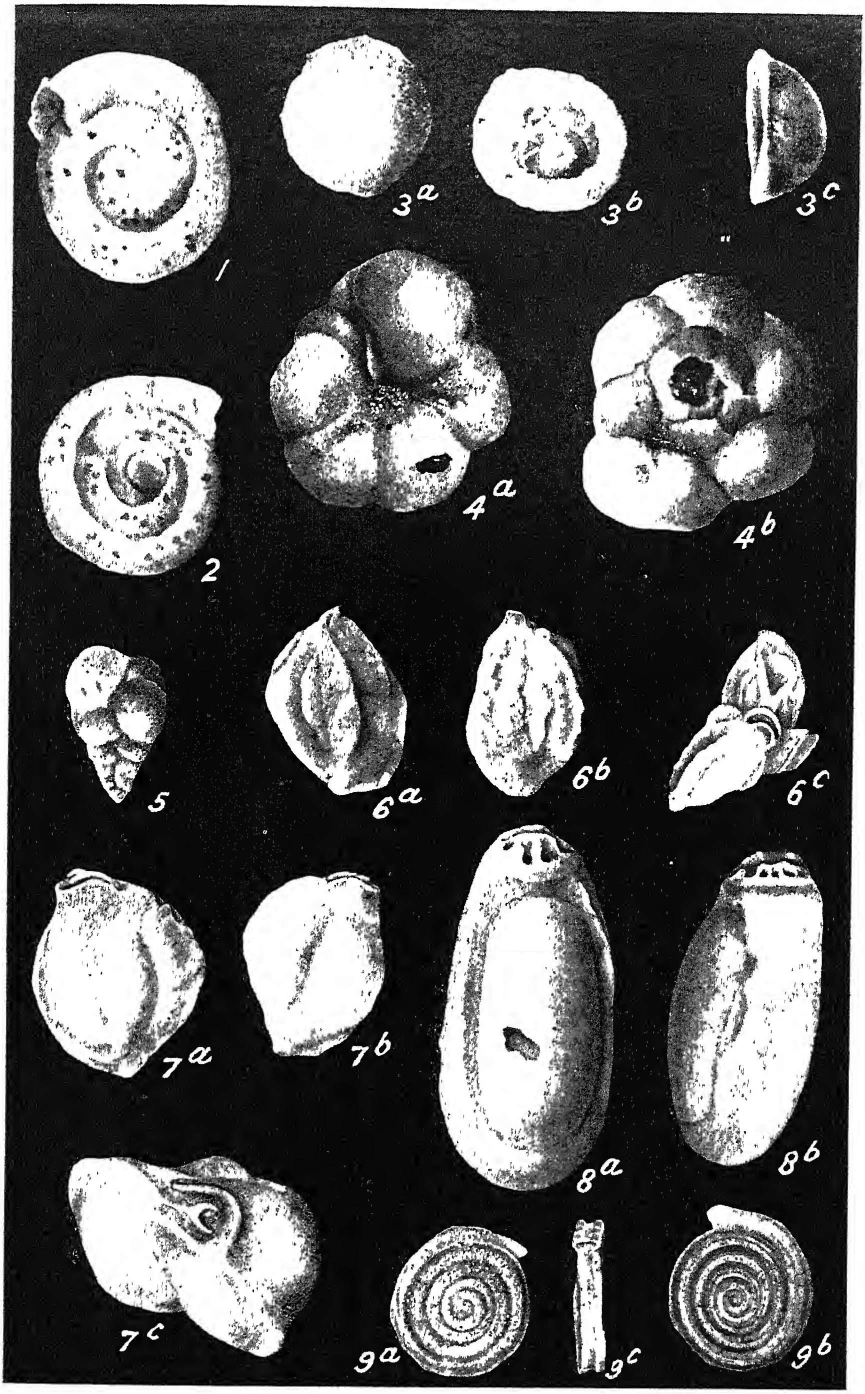
Fig. 3—*Quinqueloculina baragwanathi*, sp. nov Front view. × 43.

Fig. 4.—*Vaginulina bassensis*, sp. nov. Holotype. × 43.

Fig. 5.—*Dentalina mutsui* Hada. × 43.

Fig. 6.—*Lagena distoma-margaritifera* Parker and Jones, var. *victoriensis*, nov. Holotype of variety. × 43.

Fig. 7.—*Elphidium argenteum*, sp. nov. Holotype, *a*, side view; *b*, apertural view. × 43.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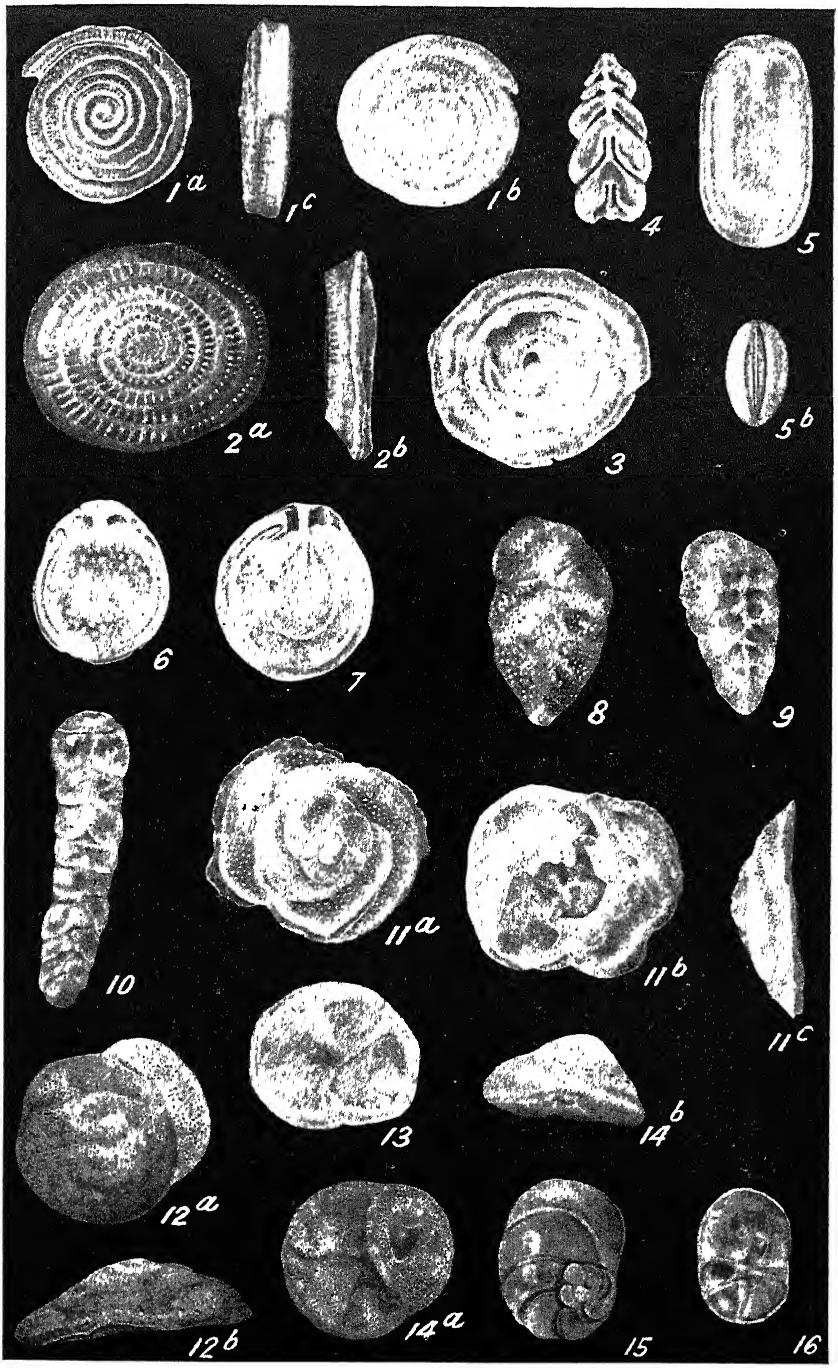
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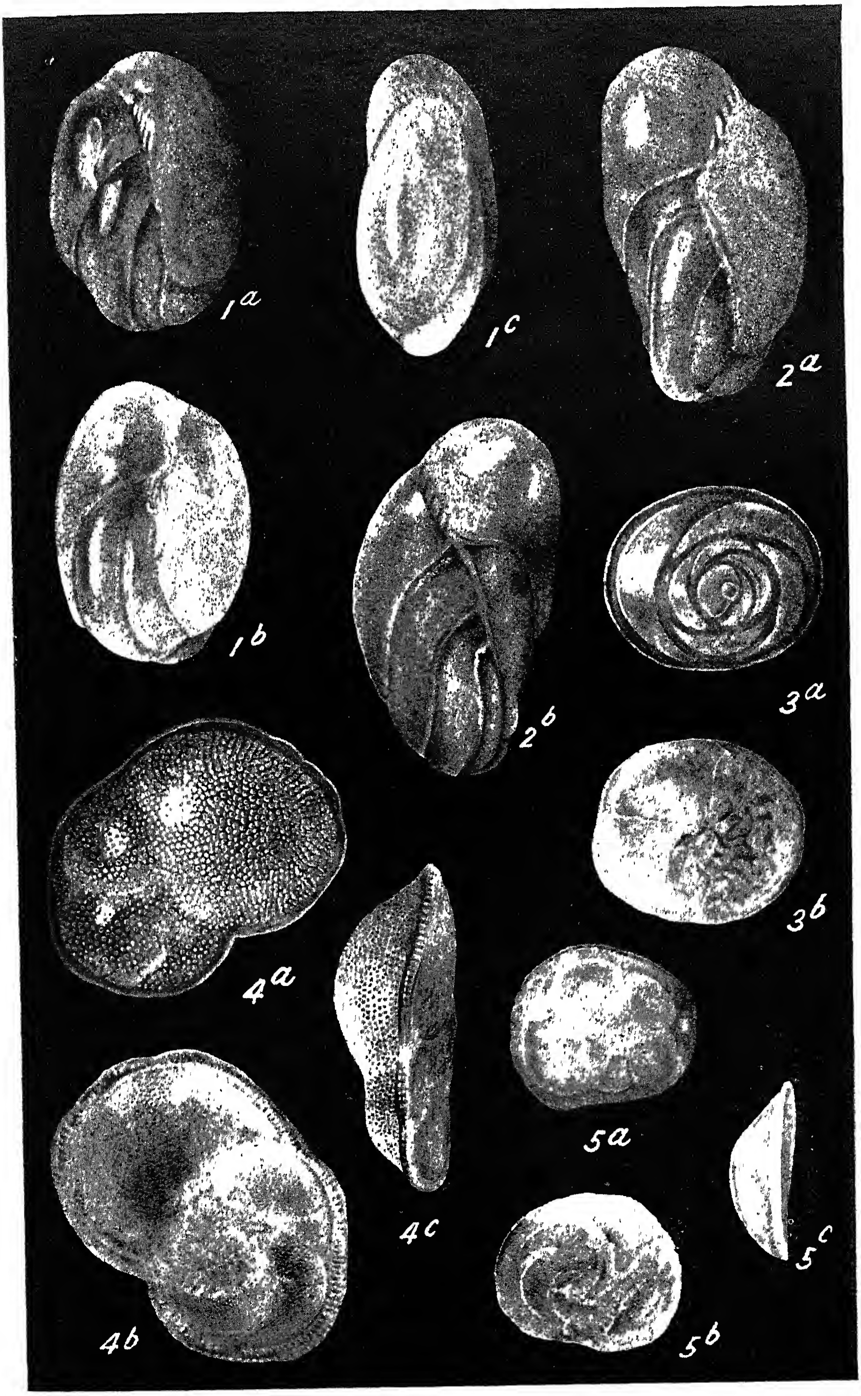
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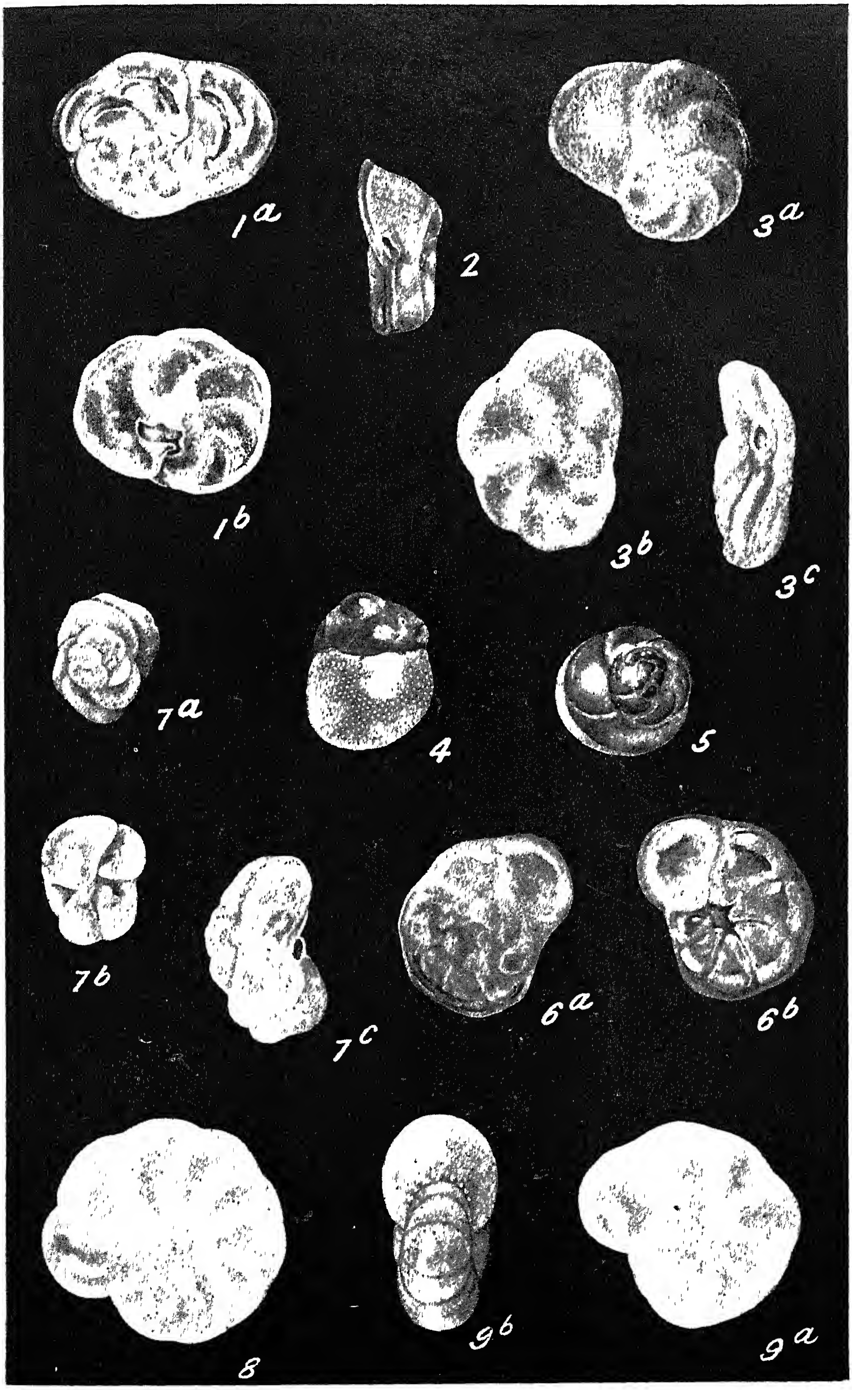
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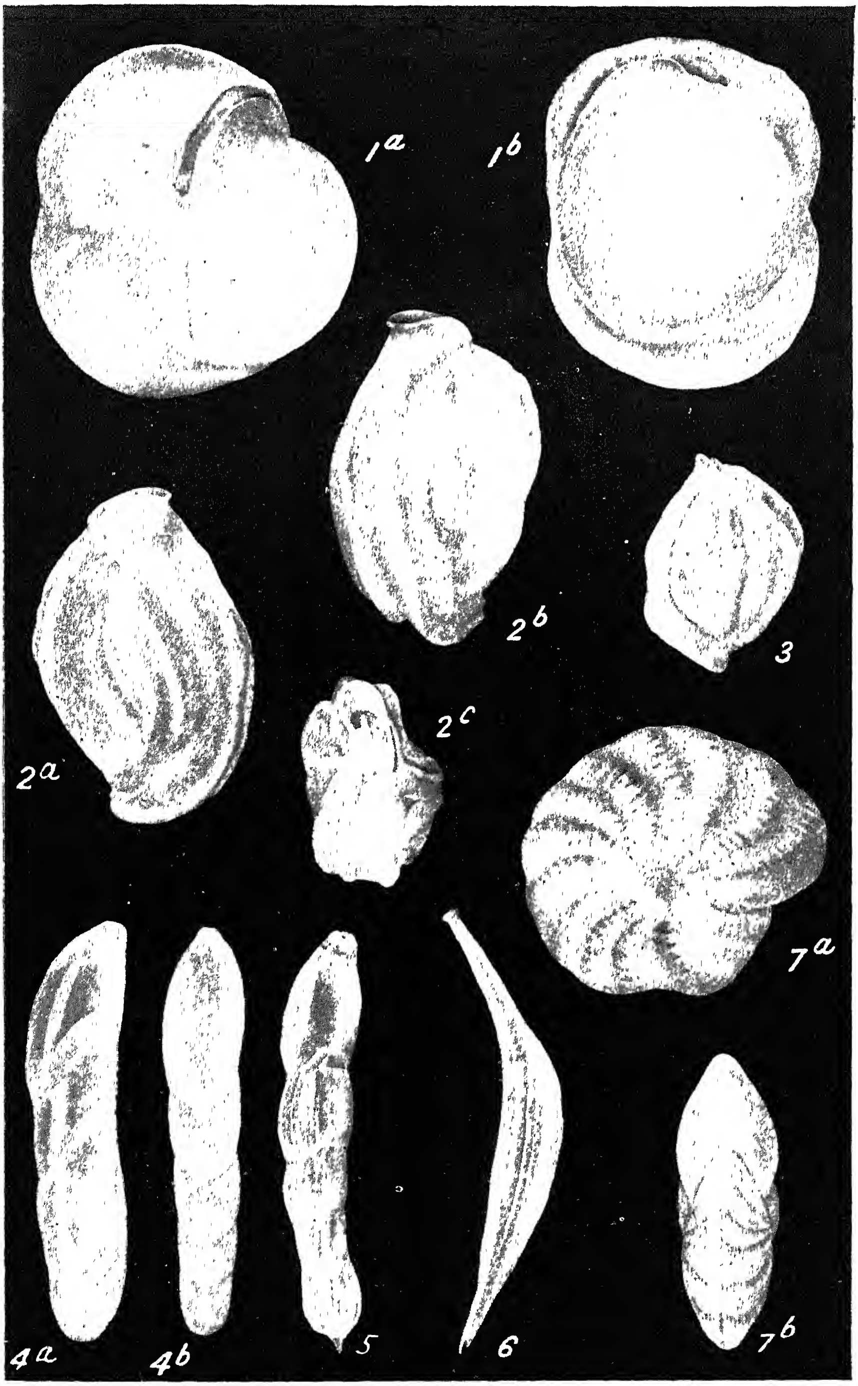
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[PROC. ROY. SOC. VICTORIA, 56 (N.S.), PT. II., 1945.]

# ART.—XIII.—*A Catalogue of Type and Figured Specimens of Fossils in the Melbourne University Geology Department.*

By F. A. SINGLETON, D.Sc.

[Read 9th December, 1943; issued separately 30th June, 1945.]

## Abstract.

The Geological Museum of Melbourne University contains more than 200 primary or supplementary type specimens. These are listed under the appropriate species, which are arranged alphabetically under larger biological groups. For each, the literature, geological horizon, locality and source are given. The new terms, tectoholotype, tectosyntype, and tectohypotype are proposed.

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## Introduction.

The importance in systematics of type material, as the ultimate basis of nomenclatural species, is now generally recognized. It follows that not only should such type material be carefully preserved in museums, but also that information as to the type specimens contained in each museum should be made generally available.

The catalogue which follows is an endeavour by the author, as curator of the Geological Museum of the University of Melbourne, Australia, to furnish this information for the primary and supplementary type specimens registered in its fossil collections. All registered fossils bear the register number in black ink or in white paint, while type specimens are distinguished by small painted discs which are red in the case of holotypes and syntypes, and green in the case of paratypes and hypotypes. Thin sections of fossils are catalogued separately and bear an independent series of register numbers, but those used in descriptions or figures (tectotypes) are marked as above.

In general, the terminology is that recommended by Frizzell (2), with the addition of Chapman's (1) terms *tectotype* and *tectoparatype*, which were not included in Frizzell's most useful list of terms, and of the new terms *tectoholotype*, *tectosyntype*, and *tectohypotype* herein proposed. These are defined together with definitions, taken from Frizzell's and Chapman's papers above cited, of the other terms used in this catalogue.

## Primary Types.

*Holotype*—a single specimen (or fragment) upon which a species is based.

*Paratype*—a specimen, other than the holotype, upon which an original specific description is based.

*Syntype*—any specimen of the author's original material when no holotype was designated; or any of a series of specimens described as "cotypes" of equal rank.

## Supplementary Types.

*Hypotype*—a described or figured specimen, used in publication in extending or correcting the knowledge of a previously defined species.

*Plastotype*—any artificial specimen moulded directly from a type.

*Tectotype*—a specimen, fragmentary or otherwise, which is selected to elucidate the microscopic structure, internal or external, of a species or genus (1, p. 62).

Chapman further states, "A tectotype may be associated, in the case of a species, with the original types (tectoparatype), or with subsequently described specimens (tectoplesiotype)." For this latter term is here substituted *tectohypotype,* in view of the objections to Cossmann's term plesiotype urged by Frizzell (2, pp. 653, 662). In the case of some fossils, notably the stromatoporoids, the original descriptions are commonly based entirely upon thin sections. It seems to the writer that these latter (tectotypes), when prepared from holotype or syntype material, should be termed *tectoholotypes* and *tectosyntypes,* respectively, to distinguish them from those prepared from paratypes, to which the term *tectoparatype* may be restricted. Those who disagree with this proposal will doubtless use tectoparatype to cover all three categories, and should make the necessary changes in the present catalogue, which contains, in addition to type material, figured specimens of fossils not referred to a species, and also a few Recent specimens specifically named and figured in comparison with fossils.

In each biological group the species are arranged alphabetically in order first of generic and then of trivial names. The species name in heavy face type on the left is that under which the type material listed under it was first described. It is, therefore, not necessarily (except in the case of primary types) the earliest name of the species, nor is it necessarily the correct name. Where this latter is known, it is placed on the same line on the right. In several cases, however, notably in the mollusca, the generic location is believed to require alteration but the correct genus for reception of the species has not yet been determined.

Beneath each species name are given references, not necessarily exhaustive, to the literature, and the synonymy. Then follow the register number and other details of the type material in the University of Melbourne, the geological age, not necessarily that attributed by the original author; the locality; and the source of the specimens. In a few instances, explanatory remarks are added. It has been impossible to check some of the references to overseas publications, and the author will be grateful for the pointing out of errors in these or other references.

## Papers Cited.

1. F. CHAPMAN.—What are Type Specimens? How should they be named? *Victorian Naturalist,* xxix. (4), pp. 59-64, August, 1912.

2. D. L. FRIZZELL.—Terminology of Types. *American Midland Naturalist,* xiv. (6), pp. 637-668, November, 1933

## PLANTAE.

**Antarcticoxylon Priestleyi** Seward, 1914:—**Rhexoxylon Priestleyi** (Seward, 1914).

*Antarcticoxylon Priestleyi* A. C. Seward, Brit. Antarctic ("Terra Nova") Exped., 1910, Geology, 1 (1), p. 17, text fig. 3 (p. 6), pls 4–7, 8 (pars), 1914.

M.U.G.D. No. 1642. PORTION OF HOLOTYPE in British Museum (Nat. Hist.) Lond.

(?) Permian (Beacon Sandstone series).

West side of medial moraine on Priestley Glacier, Terra Nova Bay, South Victoria Land, Antarctica.

Coll by Northern Party, Scott's Second Expedition, and pres. by R. E Priestley, 1935.

Obs.—A small piece from a block in the possession of Dr. Priestley, collected during extraction of the original specimen.

**Calamites Macnabi** Pritchard, 1910.

*Calamites macnabi* G. B. Pritchard, Proc. Roy. Soc. Vic., n s., 22 (2), p. 261, April, 1910.

M.U.G.D. No. 1851. HOLOTYPE, unfigured.

Permo-Carboniferous [Permian?].

"Lower Gangamopteris quarry overlooking the Korkuperrimal Valley" (Pritchard, loc. cit., 1910) =Lower quarry (Morton's quarry), Bald Hill near Bacchus Marsh, Victoria.

The type material, which is very poorly preserved, consists of about a dozen pieces of sandstone which Dr. Pritchard (verbal communication, 11.10.39) states are all from one face of a block.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Rhexoxylon Priestleyi** (Seward, 1914).

See *Antarcticoxylon Priestleyi* Seward, 1914.

## PORIFERA.

**Protospongia reticulata** T. S. Hall, 1889.

*Protospongia reticulata* T. S Hall, Proc. Roy. Soc. Vic., n.s., 1, p. 60, pl. 4, figs. 1, 2, June, 1889.

M.U.G.D. No. 1082. HOLOTYPE, figured by Hall, loc. cit., 1889.

Lower Ordovician (Bendigonian).

Ironbark, Sandhurst [= Bendigo], Victoria.

Coll. J. E. G. Edwards. Exch. with School of Mines, Bendigo.

**Receptaculites australis** Salter, 1859.

*Receptaculites australis* J. W. Salter, Figures and Descriptions of Canadian Organic Remains, Decade 1, Geol. Surv. Canada, p. 47, pl 10, figs. 8-10, 1859 R. Etheridge and W. S Dun, Rec Geol. Surv. N. S. Wales, 6, p. 62, pls. 8-10, 1898. F. Chapman, Proc. Roy. Soc. Vic., n s., 18 (1), p. 7, pl 2, figs. 2, 4-7; pl. 3; pl. 4, figs. 2-7, 1905. J. Shirley, Quart Journ. Geol. Soc. Lond, 94 (4), p. 461, pl. 40, figs. 1-4, 1938. E. D. Gill, Proc. Roy. Soc. Vic., n.s., 54 (1), p. 35, pl. 5, figs 2, 4, 5, 1942.

M.U.G.D. No. 1716. HYPOTYPE, figured by Gill, loc. cit., figs. 2, 4, 1942.

M.U.G.D. No. 1717. HYPOTYPE, counterpart of 1716, figured by Gill, loc. cit., fig. 5, 1942.

Lower Devonian (Yeringian).

Hull Road, Mooroolbark, Victoria. E. D Gill's Locality No. 13 (Proc. Roy Soc. Vic., n.s., 52 (2), pp. 252 et seq., 1940).

Pres. Rev. E. D. Gill, 24.5.41.

## STROMATOPOROIDEA.

### **Actinostroma compactum** Ripper, 1933.

*Actinostroma compactum* E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 45 (2), p. 153, figs. 5A, B (p. 163), 1st August, 1933. E. A. Ripper, *ibid.*, 50 (1), p. 15, pl. 2, figs. 7, 8, 1937.

M.U.G.D. No. 767. PARATYPE, source of Fossil Sections Nos. 233, 234.

M.U.G.D. No. 767A. Vertical section of paratype No. 767

M.U.G.D. No. 767B. Tangential section of paratype No. 767.

M.U.G.D. Fossil Section Coll. No. 233. TECTOPARATYPE, vertical section, unfigured, of paratype No 767.

M.U.G.D. Fossil Section Coll. No. 234. TECTOPARATYPE, tangential section, unfigured, of paratype No. 767.

Lower Devonian (Yeringian).

Mitchell's Quarry, Cave Hill, Lilydale, Victoria.

Sections Nos. 767A and B, though cut from the paratype, were not used in the original work and are therefore not regarded as tectoparatypes.

M.U G.D. No 1617. HYPOTYPE, source of Fossil Sections Nos. 154, 155.

M.U.G D. Fossil Section Coll. No. 154. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., fig. 7, 1937, of hypotype No. 1617.

M U G.D Fossil Section Coll. No. 155. TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit, fig. 8, 1937, of hypotype No. 1617.

Middle Devonian.

Heath's Quarry, Buchan, Victoria

Coll. Miss E. A. Ripper, M.Sc., 1933 (Field No. 167).

### **Actinostroma contortum** Ripper, 1937.

*Actinostroma contortum* E. A Ripper, Proc. Roy. Soc Vic., n.s., 50 (1), p. 14, pl. 2, figs. 3-6, 29th December, 1937.

M.U.G D. No. 1611. HOLOTYPE, source of Fossil Section No. 106.

M.U.G D Fossil Section Coll. No. 106 TECTOHOLOTYPE, vertical section, figured by Ripper, loc. cit., fig. 3, and tangential section, fig. 4, 1937, of holotype No 1611.

Middle Devonian.

Heath's Quarry, Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 122).

M.U.G.D. No. 1604. PARATYPE (finer variety), source of Fossil Sections Nos. 38, 39, 41.

M.U.G.D. Fossil Section Coll. No. 38. TECTOPARATYPE, tangential section, figured by Ripper, loc. cit., fig. 6, 1937, of paratype No. 1604.

M.U.G.D. Fossil Section Coll. No. 39. TECTOPARATYPE, vertical section, figured by Ripper, loc. cit., fig. 5, 1937, of paratype No. 1604.

M.U.G.D Fossil Section Coll. No. 41. Vertical section, unfigured, of paratype No. 1604.

Middle Devonian.

Rocky Camp, Commonwealth Quarries, Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 32).

### **Actinostroma stellulatum** Nicholson var. **distans** Ripper, 1937.

*Actinostroma stellulatum* Nicholson, variety *distans* E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 50 (1), p. 12, pl. 2, figs. 1, 2, 29th December, 1937.

M.U.G.D. No. 1610. HOLOTYPE, source of Fossil Sections Nos. 102-105.

M.U.G.D. Fossil Section Coll. No. 102 TECTOHOLOTYPE, tangential section, figured by Ripper, loc. cit., fig. 2, 1937, of holotype No. 1610.

M.U G.D. Fossil Section Coll. No. 103. TECTOHOLOTYPE, vertical section, figured by Ripper, loc. cit., fig. 1, 1937, of holotype No. 1610.

Middle Devonian.

Heath's Quarry, Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 121).

## Actinostroma verrucosum (Goldfuss, 1826).

*Ceriopora verrucosa* G. A. Goldfuss, Petrefacta Germaniae, 1, p. 33, pl. 10, fig. 6, 1826.

*Stromatopora verrucosa* Goldfuss: W. Quenstedt, Petrefakten Deutschlands, 5, p. 560, pl. 141, fig. 10, 1878. A. Bargatzky, Die Stromatoporen des rheinischen Devons, p. 55, 1881.

*Actinostroma verrucosum* Goldfuss: H. A. Nicholson, Ann. Nat. Hist., [5] 17, p. 228, 1886. H. A. Nicholson, Mon. Brit. Strom., pt. 2, Palaeontogr. Soc Lond., 42, for 1888, p. 134, pl. 16, figs. 1-8, 1889. E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 45 (2), p. 154, text figs. 1 (p. 155), 5C, D (p. 163), 1933.

M.U.G.D. No. 1446. HYPOTYPE, source of Fossil Sections Nos. 237, 238.

M.U.G.D. Fossil Section Coll. No. 237. TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit., fig. 5D, 1933, of hypotype No. 1446.

M.U.G.D. Fossil Section Coll. No. 238. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., figs. 1, 5C, 1933, of hypotype No. 1446.

Lower Devonian (Yeringian).

Mitchell's Quarry, Cave Hill, Lilydale, Victoria.

Coll. Miss E. A. Ripper, and pres. 24.10.32.

## Clathrodictyon calamosum Ripper, 1933.

*Clathrodictyon calamosum* E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 45 (2), p. 160, text-figs. 6E, F (p. 164), 1st August, 1933.

M.U.G.D. No. 1448. PARATYPE, source of Fossil Sections Nos. 239, 240.

M.U.G.D. Fossil Section Coll. No. 239. Tangential section, unfigured, of paratype No. 1448.

M.U.G.D. Fossil Section Coll. No. 240. Vertical section, unfigured, of paratype No. 1448.

Lower Devonian (Yeringian).

Mitchell's Quarry, Cave Hill, Lilydale, Victoria.

Coll. Miss E. A. Ripper, and pres. 24.10.32.

## Clathrodictyon aff. chapmani Ripper, 1933.

*Clathrodictyon chapmani* E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 45 (2), p. 159, text-figs. 4 (p. 158), 6C, D (p. 164), 1st August, 1933.

*Clathrodictyon* aff. *chapmani* E. A. Ripper, *ibid.*, 50 (1), p. 3, pl. 1, figs. 3, 4, 1937.

M.U.G.D. No. 1598. HYPOTYPE, source of Fossil Sections Nos. 168, 169.

M.U.G.D. Fossil Section Coll. No. 168. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., fig. 3, 1937, of hypotype No. 1598.

M.U.G.D. Fossil Section Coll. No. 169. TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit., fig. 4, 1937, of hypotype No. 1598.

Lower Devonian.

Griffith's Quarry, Allot. 131, Loyola, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 92).

**Clathrodictyon clarum** Počta, 1894.

*Clathrodictyon clarum* P Počta, Syst. Sil du Centre de la Bohême, 8 (1), p. 152, pl. 18, figs. 7, 8, 1894 P. Počta, Sitzungsber. Königl. Bohm. Gesells. d. Wissensch. Prag, No. 12, p. 1 and pl., 1910. D. Le Maitre, Mém. Soc. Géol. France, n s., 9 (1), Mém. 20, p. 16, pl. 4, figs. 1-5, 1933. E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 50 (1), p. 21, pl. 4, figs. 3, 4, 1937.

M.U.G.D. No. 1605. HYPOTYPE, source of Fossil Sections Nos. 53, 54.

M.U.G.D. Fossil Section Coll. No. 53. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., fig. 3, 1937, of hypotype No. 1605.

M.U.G.D. Fossil Section Coll. No. 54. TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit., fig. 4, 1937, of hypotype No. 1605.

Middle Devonian.

Rocky Camp, Commonwealth Quarries, Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 48).

**Clathrodictyon confertum** Nicholson, 1889.

*Clathrodictyon confertum* H. A Nicholson, Mon. Brit. Strom., pt 2, Palaeontogr. Soc. Lond., 42, for 1888, p. 154, pl 18, figs. 13, 14, March, 1889 K. Boehnke, Palaeontographica, 61, p 170, figs. 15, 16, 1915. E. A. Ripper, Proc. Roy Soc. Vic., n s., 50 (1), p. 18, pl. 3, fig. 3, 1937.

M U G.D No. 1607. HYPOTYPE, source of Fossil Sections Nos. 88, 89.

M.U.G.D. Fossil Section Coll. No. 88. Vertical section, unfigured, of hypotype No. 1607.

M.U.G.D. Fossil Section Coll. No. 89. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit, 1937, of hypotype No. 1607.

Middle Devonian.

Cameron's Quarry, South Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 78).

**Clathrodictyon convictum** Yavorsky, 1929.

*Clathrodictyon convictum* B. Yavorsky, Bull. Com. Géol. Leningrad, 48 (1), pp. 91, 105, pl. 6, fig. 10; pl. 9, figs. 5-7, 1929. E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 50 (1), p. 19, pl. 3, figs. 4-8, 1937.

M U.G.D. No. 1613. HYPOTYPE, source of Fossil Sections Nos. 117, 118.

M.U.G.D. No. 1616. HYPOTYPE, source of Fossil Sections Nos. 146, 147.

M.U.G.D. Fossil Section Coll No. 117. TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit., fig. 8, 1937, of hypotype No 1613.

M.U.G.D. Fossil Section Coll. No. 118. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., fig. 7, 1937, of hypotype No. 1613.

M.U.G.D. Fossil Section Coll. No. 146. TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit., fig. 6, 1937, of hypotype No. 1616.

M.U.G.D. Fossil Section Coll, No. 147. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., figs. 4 and 5, 1937, of hypotype No. 1616.

Middle Devonian.

Heath's Quarry, Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field Nos. 129 = Reg. No. 1613, and 157 = Reg. No. 1616).

**Clathrodictyon convictum** Yavorsky var. **delicatula** Ripper, 1937.

*Clathrodictyon convictum* Yavorsky variety *delicatula* E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 50 (1), p. 20, pl. 4, figs. 1, 2, 29th December, 1937.

M.U.G.D. No. 1606. Holotype, source of Fossil Section No. 63.

M.U.G.D Fossil Section Coll. No. 63. Tectoholotype, vertical section, fig. 1, and tangential section, fig. 2, figured by Ripper, loc. cit., 1937, of holotype No. 1606 (given erroneously as No. 1660 by Ripper, loc. cit., 1937, in explanation of plate 4, fig. 1).

Middle Devonian.

Rocky Camp, Commonwealth Quarries, Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 56).

**Clathrodictyon regulare** (von Rosen, 1867).

*Stromatopora regularis* F. von Rosen, Ueber die Natur der Stromatoporen, p. 74, pl. 9, figs. 1-4, 1867.

*Clathrodictyon regulare* Rosen sp.: H. A. Nicholson, Ann. Mag. Nat. Hist., [5] 19, p. 10, pl. 2, figs. 5, 6, 1887. H. A. Nicholson, Mon. Brit. Strom., pt. 2, Palaeontogr. Soc. Lond., 42, for 1888, p. 155, pl. 18, figs. 8-11*a*, 1889. P. E. Vinassa de Regny, Palaeontographia italica, 14, p. 182, pl. 21 (1), figs. 18-20, 1908. K. Boehnke, Palaeontographica, 61, p. 168, text-fig. 12, 1915. D. Le Maitre, Mém. Soc. Géol. du Nord, 12, p. 39; p. 185, pl. 12, figs. 1-6, 1934. E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 50 (1), p. 2, pl. 1, figs. 1, 2, 1937. E. A. Ripper, *ibid.*, p. 16, pl. 3, figs. 1, 2, 1937.

M.U.G.D. No. 1599. Hypotype, source of Fossil Sections Nos. 175, 176.

M.U.G.D. Fossil Section Coll. No. 175. Tectohypotype, vertical section, figured by Ripper, loc. cit., pl. 1, fig. 1, 1937, of hypotype No. 1599.

M.U.G.D. Fossil Section Coll. No. 176. Tectohypotype, tangential section, figured by Ripper, loc. cit., pl. 1, fig. 2, 1937, of hypotype No. 1599.

Lower Devonian.

Griffith's Quarry, Allot. 131, Loyola, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 97).

M.U.G.D. No. 1618. Hypotype, source of Fossil Sections Nos. 156, 157.

M.U.G.D. Fossil Section Coll. No. 156. Tectohypotype, vertical section, figured by Ripper, loc. cit., pl. 3, fig. 1, 1937, of hypotype No. 1618.

M.U.G.D. Fossil Section Coll. No. 157. Tectohypotype, tangential section, figured by Ripper, loc. cit., pl. 3, fig. 2, 1937, of hypotype No. 1618.

Middle Devonian.

Heath's Quarry, Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 168).

**Hermatostroma episcopale** Nicholson, 1892.

*Hermatostroma episcopale* H. A. Nicholson, Mon. Brit. Strom., pt. 4, Palaeontogr. Soc. Lond., 46, for 1892, p. 219, pl. 28, figs. 4-11, November, 1892. De Le Maitre, Mém. Soc. Géol. du Nord, 12, p. 198, pl. 15, figs. 5, 6; pl. 16, figs. 1, 2, 1934. E. A. Ripper, Proc. Roy. Soc. Vict., n.s., 50 (1), p. 29, pl. 5, figs. 7, 8, 1937.

M.U.G.D. No. 1612. Hypotype, source of Fossil Sections Nos. 113, 114.

M.U.G.D. Fossil Section Coll. No. 113. Tectohypotype, tangential section, figured by Ripper, loc. cit., fig. 8, 1937, of hypotype No. 1612.

M.U.G.D. Fossil Section Coll. No. 114. Tectohypotype, vertical section, figured by Ripper, loc. cit., fig. 7, 1937, of hypotype No. 1612.

Middle Devonian.

Heath's Quarry, Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 126).

**Hermatostroma episcopale** Nicholson var. **buchanensis** Ripper, 1937.

*Hermatostroma episcopale* H. A. Nicholson variety *buchanensis* E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 50 (1), p. 32, pl. 5, figs. 9, 10, 29th December, 1937.

M.U.G.D. No. 1602. SYNTYPE, source of Fossil Sections Nos. 20, 21.

M.U.G.D. No. 1603. SYNTYPE, source of Fossil Sections Nos. 27, 28.

M.U.G.D. Fossil Section Coll. No. 20. TECTOSYNTYPE, vertical section, figured by Ripper, loc. cit., fig. 9, 1937, of syntype No. 1602.

M.U.G.D. Fossil Section Coll. No. 21. Tangential section, unfigured, of syntype No. 1602.

M.U.G.D. Fossil Section Coll. No. 27. Vertical section, unfigured, of syntype No. 1603.

M.U.G.D. Fossil Section Coll. No. 28. TECTOSYNTYPE, tangential section, figured by Ripper, loc. cit., fig. 10, of syntype No. 1603.

Middle Devonian.

Near Hicks', Murrindal, Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field Nos. 18 = Reg. No. 1602, and 23 = Reg. No. 1603).

**Stromatopora concentrica** Goldfuss, 1826.

*Stromatopora concentrica* G. A. Goldfuss, Petrefacta Germaniae, 1, p. 22, pl. 8. figs. 5*a-c*, 1826. H. A. Nicholson, Mon. Brit. Strom., pt. 1, Palaeontogr. Soc Lond., 39, for 1885, p. 2; pl. 11, figs. 15-18, 1886. Waagen, W., and Wentzel, J., Palaeontologia Indica, series 13 (Salt-Range Fossils), 1 (7), p. 927, pl. 120, figs. 4*a*, *b*, 5*a*, *b*, pl. 121, figs. 1*a-c*, 1888. H. A. Nicholson, Mon. Brit. Strom., pt. 3, Palaeontogr. Soc Lond., 44, for 1890, p. 164, pl. 20, fig. 10-12, pl. 21; figs. 1-3, pl. 24, figs. 9, 10, 1891. P. E. Vinassa de Regny, Boll. R. Com. geol d'Ital. 41, p. 46, pl. 1, fig. 6, 1910. M. Gortoni, Riv. ital. di Paleont., 18, p 123, pl. 4, figs. 6, 7, 1912. K. Boehnke, Palaeontographica. 61, p. 180, text-figs. 30, 31, 1915. P. E. Vinassa de Regny, Paleont. italica, 24, p. 113, pl. 11 (6), figs. 3-5, 1919. V. Riabinin, Bull. Unit. Geol. and Prospecting Service U.S.S.R., 51, pt. 58, p. 860, pl. 2, figs. 5, 6, 1932. D. Le Maitre, Mém. Soc. Géol. du Nord, 12, p. 197, pl. 13, figs. 6, 7, 1934. E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 50 (1), p. 24, pl. 4, figs. 7, 8; pl. 5, figs. 1, 2, 1937.

M.U.G.D. No. 1608. HYPOTYPE, source of Fossil Sections Nos. 69, 70.

M.U.G.D. Fossil Section Coll. No. 69. TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit., fig. 8, 1937, of hypotype No. 1608.

M.U.G.D. Fossil Section Coll. No. 70. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., fig. 7, 1937, of hypotype No. 1608.

Middle Devonian.

Rocky Camp, Commonwealth Quarries, Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 241).

M.U.G.D. No. 1615. HYPOTYPE, source of Fossil Sections Nos. 132, 133.

M.U.G.D. Fossil Section Coll. No. 132. TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit., fig. 2, 1937, of hypotype No. 1615.

M.U.G.D. Fossil Section Coll. No. 133. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., fig. 1, 1937, of hypotype No. 1615.

Middle Devonian.

Heath's Quarry, Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 146).

**Stromatopora concentrica** Goldfuss var. **colliculata** Nicholson, 1886.

*Stromatopora concentrica* G. A. Goldfuss variety *colliculata* H. A. Nicholson, Mon. Brit. Strom., pt. 1, Palaeontogr. Soc. Lond., 39, for 1885, pl. 3, fig. 5, January, 1886 H. A. Nicholson, *idem.*, pt. 3, *ibid.*, 44, for 1890, p. 165, 1891. E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 50 (1), p. 26, pl. 5, figs. 3, 4, 1937.

M.U.G.D. No. 1614. HYPOTYPE, source of Fossil Sections Nos. 121, 122.

M.U.G.D. Fossil Section Coll. No. 121. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., fig. 3, 1937, of hypotype No. 1614.

M.U.G.D. Fossil Section Coll. No. 122 TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit., fig. 4, 1937, of hypotype No. 1614.

Middle Devonian.

Heath's Quarry, Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 138).

**Stromatopora foveolata** (Girty, 1895).

*Syringostroma foveolatum* G H. Girty, Ann Rept. New York State Mus., 48 (2), for 1894, p. 295, pl. 6, figs. 8, 9, 1895.

*Stromatopora foveolata* (Girty): W. A Parks, Univ. Toronto Studies, Geol. Series 6, p. 20, pl. 17, figs. 5-7, pl. 18, figs. 4, 10, 1909. E. A. Ripper, Proc. Roy. Soc. Vic, n.s., 49 (2), p. 185, text figs. 2A, B (p. 186), 1937.

M.U.G.D. No. 768. HYPOTYPE, source of Fossil Sections Nos. 235, 236.

M.U.G.D. Fossil Section Coll. No. 235. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., fig. 2A, 1937, of hypotype No. 768.

M.U.G.D. Fossil Section Coll. No. 236. TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit., fig. 2B, 1937, of hypotype No. 768.

Lower Devonian (Yeringian).

Mitchell's Quarry, Cave Hill, Lilydale, Victoria.

**Stromatopora hüpschii** (Bargatzky, 1881).

*Caunopora hüpschii* A. Bargatzky, Die Stromatoporen des rheinischen Devons, p. 62, 1881.

*Stromatopora hüpschii* Bargatzky sp.; H. A. Nicholson, Mon. Brit. Strom., pt. 1, Palaeontogr. Soc. Lond., 39, for 1885, figs. 6*a*, *b* (p. 50); pl. 10, figs. 8, 9, 1886. H. A. Nicholson, *idem*, pt. 3, *ibid.*, 44, for 1890, p. 176, fig. 20*a*, *b*, (p. 177); pl. 22, figs. 3-7, 1891. P. E. Vinassa de Regny, Palaeontographia italica, 24, p. 113, pl. 12 (7), figs. 5, 6, 1919.

*Stromatopora* aff. *hüpschii* (Bargatzky): E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 49 (2), p. 186, pl. 8, figs. 7, 8, 1937.

*Stromatopora hüpschii* (Bargatzky): E. A. Ripper, *ibid*, 50 (1), p. 28, pl. 5, figs. 5, 6, 1937.

M.U.G.D. No. 1601. HYPOTYPE, source of Fossil Sections Nos. 3, 4.

M.U.G.D. Fossil Section Coll. No. 3. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., fig. 5, 1937, of hypotype No. 1601.

M.U.G.D. Fossil Section Coll. No. 4. TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit., fig. 6, 1937, of hypotype No. 1601.

Middle Devonian.

Citadel Rocks, Murrindal River, Buchan, Victoria.

Coll. Miss E. A. Ripper, 1933 (Field No. 3).

## Stromatoporella granulata (Nicholson, 1873).

*Stromatopora granulata* H. A. Nicholson, Ann. Mag. Nat Hist.. [4] 12, p. 94, pl. 4, figs. 3, *3a*, 1873. H. A. Nicholson, ibid., [5] 18, p. 10, 1886.

*Stromatoporella granulata* H. A. Nicholson, Mon. Brit. Strom., pt. 1, Palaeontogr Soc. Lond., 39, for 1885, pl. 1, figs. 4, 5; pl. 4, fig. 6; pl. 7, figs. 5, 6, 1886. H. A. Nicholson, *idem*, pt. 3, *ibid.*, 44, for 1890, p. 202, 1891. H. A. Nicholson, *idem*, pt 4, *ibid.*, 46, for 1892, p 203, pl. 26, figs. 1, *1a*, *b*, 1892. W. A. Parks, Univ. Toronto Studies, Geol Ser., 39, p. 95, pl. 15, figs 6, 7; pl. 16, figs. 1-7, 1936. E A. Ripper, Proc Roy Soc Vic., n.s., 49 (2), p. 191, pl. 9, figs 3-5, 1937.

M.U G.D. No. 1622. HYPOTYPE, source of Fossil Sections Nos. 200, 201.

M.U.G.D. Fossil Section Coll. No. 200. TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit., fig. 5, 1937, of hypotype No. 1622.

M.U.G.D. Fossil Section Coll. No. 201. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., figs. 3, 4, 1937, of hypotype No. 1622.

Lower Devonian (Yeringian).

Mitchell's Quarry, Cave Hill, Lilydale, Victoria.

Coll. Miss E. A. Ripper.

## Syringostroma densum Nicholson, 1875.

*Syringostroma densa* H. A. Nicholson, Rept. Geol. Surv. Ohio, 2 (2), Palaeontology, p. 251, pl. 24, figs. 2, *2a*, *b*, 1875.

*Syringostroma densum* H A. Nicholson, Mon. Brit. Strom., pt. 1, Palaeontogr. Soc. Lond., 39, for 1885, p. 97, pl. 11, figs. 13, 14, 1886. H. A. Nicholson, Ann. Mag. Nat. Hist, [6] 7, p 326, pl. 10, figs. 8, 9, 1891. E A. Ripper, Proc Roy. Soc. Vic., n.s., 49 (2), p. 182, pl. 8, figs. 3-5, 1937.

M.U.G.D. No. 1620. Hypotype, source of Fossil Sections Nos. 225, 226.

M.U.G.D. Fossil Section Coll. No. 225. TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit., figs. 4, 5, 1937, of hypotype No. 1620.

M.U G.D. Fossil Section Coll. No. 226. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., fig. 3, 1937, of hypotype No. 1620.

Lower Devonian (Yeringian).

Mitchell's Quarry, Cave Hill, Lilydale, Victoria.

Coll. A. C. Frostick and pres. 19.8 36.

## Syringostroma aff. ristigouchense (Spencer, 1884).

*Coenostroma ristigouchense* Spencer, Bull. Mus Univ. Missouri, p. 49, pl. 6, figs. 12, *12a*, 1884.

*Syringostroma ristigouchense* Spencer sp.: H. A. Nicholson, Mon. Brit. Strom., pt. 1, Palaeontogr. Soc. Lond., 39, for 1885, p. 97, pl. 11, figs. 11, 12, 1886. H. A. Nicholson, Ann. Mag. Nat. Hist., [6] 7, p. 324, pl. 8, figs. 6-8, 1891. W. A. Parks, Univ. Toronto Studies, Geol. Ser., 6, p. 10, pl. 16, figs. 3-5, 1909.

*Syringostroma* aff. *ristigouchense* (Spencer): E. A. Ripper, Proc. Roy. Soc. Vic., n.s., 49 (2), p. 181, pl. 8, figs. 1, 2, 1937.

M.U.G.D. No. 1619. HYPOTYPE, source of Fossil Sections Nos. 208, 209.

M.U.G.D. Fossil Section Coll. No. 208. TECTOHYPOTYPE, tangential section, figured by Ripper, loc. cit., fig. 2, 1937, of hypotype No. 1619.

M.U G.D. Fossil Section Coll. No. 209. TECTOHYPOTYPE, vertical section, figured by Ripper, loc. cit., fig. 1, 1937, of hypotype No. 1619.

Lower Devonian (Yeringian).

Mitchell's Quarry, Cave Hill, Lilydale, Victoria.

A piece cut from a specimen in the collection of F. S. Colliver, Melbourne

## CALYPTOBLASTEA.

### **Archaeocryptolaria recta** Chapman, 1919.

*Archaeocryptolaria recta* F. Chapman, Proc. Roy. Soc. Vic., n.s., 31 (1), p. 392, pl. 19, figs. 4, 4*a*; pl. 20, fig. 8, May, 1919. F. Chapman and D. E. Thomas, *ibid.*, 48 (2), p. 198, pl. 14, fig. 1, June, 1936.

M.U.G.D. No. 527 COUNTERPART OF HOLOTYPE in National Museum, Melbourne (No. 13111), figured by Chapman, loc. cit., 1919, and by Chapman and Thomas, loc. cit., 1936.

Middle Cambrian.

Deep Creek, 2 miles ENE. of North Monegetta, Victoria.

Coll. Prof. E. W. Skeats.

Obs.—The holotype in the National Museum is Reg. No. 13111, not 1311 as stated by Chapman and Thomas.

### **Archaeolafoea monegettae** (Chapman, 1919).

See *Mastigograptus monegettae* Chapman, 1919.

### **Archaeolafoea serialis** Chapman and Thomas, 1936.

*Archaeolafoea serialis* F. Chapman and D. E. Thomas, Proc. Roy. Soc. Vic., n.s., 48 (2), p. 201, pl. 14, figs. 9-11, pl. 15, figs. 12, 12*a*, 12*b*, June, 1936.

M.U.G.D. No. 1591. PARATYPE, figured by Chapman and Thomas, loc. cit., pl. 15, figs. 12, 12*a*, 12*b*, 1936.

M.U.G.D. No. 1592. COUNTERPART OF PARATYPE No. 1591.

Middle Cambrian.

Deep Creek, 2 miles E.N.E. of North Monegetta, Victoria.

Coll. G. Baker, 29.4.33.

### **Cactograptus flexispinosus** Chapman and Thomas, 1936.

*Cactograptus flexispinosus* F. Chapman and D. E. Thomas, Proc. Roy. Soc. Vic., n.s., 48 (2), p. 207, pl. 17, figs. 29-33, June, 1936.

M.U.G.D. No. 1593. PARATYPE, figured by Chapman and Thomas, loc. cit., pl. 17, fig. 33, 1936.

M.U.G.D. No. 1594. COUNTERPART OF PARATYPE No. 1593.

Middle Cambrian.

Deep Creek, 2 miles E.N.E of North Monegetta, Victoria.

Coll. E. S. Hills, 29.4.33.

### **Mastigograptus monegettae** Chapman, 1919:—**Archaeolafoea monegettae** (Chapman, 1919).

*Mastigograptus monegettae* F. Chapman, Proc. Roy. Soc. Vic., n.s., 31 (1), p. 391, pl. 19, figs. 2, 2*a*; pl. 20, fig. 6, May, 1919.

*Archaeolafoea monegettae* Chapman: F. Chapman and D. E. Thomas, *ibid.*, 48 (2), p. 200, pl. 14, figs. 6-8, June, 1936.

M.U.G.D. No. 528. COUNTERPART OF HOLOTYPE in National Museum, Melbourne (No. 13113), figured by Chapman, loc. cit., 1919.

Middle Cambrian.

Deep Creek, 2 miles E.N.E. of North Monegetta, Victoria.

Coll. Prof. E. W. Skeats.

## GRAPTOLITOIDEA.

### Climacograptus riddellensis Harris, 1924.

*Diplograpsus rectangularis* McCoy: F. McCoy, Prodromus Palaeont. Vic., decade 1, p. 11, pl. 11, figs. 7, 7*a*, 1874. Not *Diplograpsis* [sic] *rectangularis* M'Coy, Ann Mag. Nat. Hist., [2] 6 (34), p. 271, 1850 [ = *Climacograptus rectangularis* (McCoy)].

*Climacograptus riddellensis* W. J. Harris, Proc. Roy. Soc. Vic., n.s., 36 (2), p. 100, pl. 8, figs. 11, 12, August, 1924.

M.U.G.D. No. 647. COUNTERPART OF HOLOTYPE in National Museum, Melbourne, figured by Harris, loc. cit., fig. 11, 1924.

Upper Ordovician (Gisbornian).

Geol. Surv. Vic. Locality Ba 67, junction of Jackson's and Riddell's Creeks, about 3 miles south-east of Riddell railway station, Victoria.

Pres. W. J. Harris, 14.12.23.

### Clonograptus flexilis (J. Hall, 1858).

*Graptolithus flexilis* J Hall, Geol. Surv. Canada, Report for 1857, p. 119, 1858. J. Hall, Graptolites of the Quebec Group, Geol. Surv. Canada, decade 2, p 103, pl. 10, figs 3-9, 1865.

*Clonograptus flexilis* J. Hall. T. S. Hall, Proc Roy. Soc. Vic, n.s., 11 (2), pl. 19, fig 20, February, 1899. W. J Harris and D. E. Thomas, Min. and Geol Journ., Vic., 1 (3), pl. 1 (p 69), fig. 6, July, 1938

M.U.G.D. No. 1661. HYPOTYPE, figured by T. S. Hall, loc. cit., 1899, and copied by Harris and Thomas, loc. cit., 1938.

Lower Ordovician (Lancefieldian, Zone La 2).

Quarry, Allot. 56, Parish of Goldie, near Lancefield, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

### Clonograptus magnificus (Pritchard, 1892).

See *Temnograptus magnificus* Pritchard, 1892.

### Clonograptus rigidus (J. Hall, 1858).

*Graptolithus rigidus* J. Hall, Geol. Surv. Canada, Report for 1857, p. 121, 1858. J. Hall, Graptolites of the Quebec Group, Geol. Surv. Canada, decade 2, p. 105, pl. 11, figs. 1-5, 1865.

*Clonograptus rigidus* J. Hall: T. S. Hall, Proc. Roy. Soc Vic., n.s., 11 (2), pl. 19, fig. 21, February, 1899. W. J. Harris and D. E. Thomas, Min. and Geol. Journ., Vic., 1 (3), pl. 1 (p. 69), fig. 5, July, 1938.

M.U.G.D. No. 1660 HYPOTYPE, figured by T. S. Hall, loc. cit., 1899, and copied by Harris and Thomas, loc. cit., 1938.

Lower Ordovician (Lancefieldian, Zone La 2).

Quarry, Allot. 56, Parish of Goldie, near Lancefield, Victoria.

Purchased from Dr. G. B. Pritchard, 11 10.39.

Obs.—The specimen now lacks the uppermost part of T. S. Hall's figure, of which it is, however, undoubtedly the original, and is so marked in T. S. Hall's handwriting.

### Dichograptus expansus Harris and Thomas, 1940.

*Dichograptus expansus* W. J. Harris and D. E. Thomas, Min. and Geol. Journ., Vic., 2 (2), p. 130, pl 1 (p. 134), fig. 5; pl. 2 (p. 135), figs. 6*a*, 6*b*, January, 1940.

M.U.G.D. No. 1678. COUNTERPART OF PARATYPE in Geol. Mus. Mines Dept. Vic. (No. 42560), figured by Harris and Thomas, loc. cit., pl. 2, fig. 6*b*, 1940.

Lower Ordovician (Bendigonian, Zone Be 2).

North-west corner of Allot. 30A, Sect. II., Parish of Campbelltown, Victoria.

Coll. Thos. Smith, and pres. D. E. Thomas, 1939.

**Dichograptus octonarius** (J. Hall, 1858).

*Graptolithus octonarius* J. Hall, Geol. Surv. Canada, Report for 1857, p. 124, 1858. J. Hall, Graptolites of the Quebec Group, Geol. Surv. Canada, decade 2, p. 95, pl. 10, figs. 1, 2, 1865.

*Dichograptus octonarius* (J. Hall): W. J. Harris and D. E. Thomas, Min and Geol. Journ., Vic., 2 (2), p. 129, pl. 1 (p 134), figs. 2*a*, 2*b*; pl. 2 (p. 135), fig. 3, January, 1940.

M.U.G.D. No. 1679. Counterpart of hypotype in Geol. Mus. Mines Dept. Vic. (No. 42553), figured by Harris and Thomas, loc. cit., pl. 1, fig. 2*a;* pl. 2, fig. 3, 1940.

Lower Ordovician (Castlemainian, Zone Ca 2).

Victoria Gully, Castlemaine, Victoria.

Pres. D. E. Thomas, 1939.

**Dichograptus octonarius** (J. Hall) var. **solida,** Harris and Thomas, 1940.

*Dichograptus octonarius* var. *solida* W. J. Harris and D. E. Thomas, Min and Geol Journ., Vic., 2 (2), p. 130, pl. 1, fig. 3; pl. 2, fig. 4, January, 1940.

M U.G.D. No. 1680. Counterpart of holotype of variety in Geol. Mus. Mines Dept. Vic. (No. 42555), figured by Harris and Thomas, loc. cit., 1940.

Lower Ordovician (Yapeenian, Zone Ya 2).

Wiley's Quarry, Woodend, Victoria.

Pres. D. E. Thomas, 1939.

**Dictyonema grande** T. S. Hall, 1892.

See *Dictyonema macgillivrayi* T. S. Hall, 1897.

**Dictyonema macgillivrayi** T. S. Hall, 1897.

*Dictyonema grande* T S. Hall, Proc. Roy. Soc. Vic, n.s, 4 (1), p. 8, pls. 1, 2, April, 1892. G. B. Pritchard, *ibid.*, 7, p. 28, January, 1895. Not *Dictyonema grandis* H. A. Nicholson, Ann. Mag. Nat. Hist., [4] 11 (62), p. 134, text figs. 1*a*, 1*b* (p. 135), 1873

*Dictyonema macgillivrayi* T. S. Hall, nom. mut., Proc. Roy. Soc. Vic., n.s., 10 (1), p. 15, July, 1897. T. S. Hall, *ibid.*, 11 (2), p. 174, pl. 18, fig. 27, February, 1899. W. J. Harris and R. A. Keble, *ibid*, 44 (1), p. 47, pl. 3, February, 1932.

M.U.G.D. No. 1664. Hypotype, figured (in part) by T. S. Hall, loc. cit., 1899, and counterpart of hypotype in National Museum, Melbourne (No. 13126), figured by Harris and Keble, loc. cit., 1932. It is also the basis of the description by Pritchard, loc. cit., 1895.

Lower Ordovician (Lancefieldian, Zone La 2).

Quarry, Allot. 56, Parish of Goldie, near Lancefield, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Dictyonema pulchellum** T. S. Hall, 1899.

*Dictyonema pulchellum* T. S. Hall, Proc. Roy. Soc. Vic., n.s., 11 (2), p. 174, pl. 18, figs. 28-30, February, 1899.

M.U.G.D. No. 1656. Syntype, figured by T. S. Hall, loc. cit., pl. 18, fig. 28, 1899.

M.U.G.D. No. 1657. Syntype, figured by T. S. Hall, loc. cit., pl. 18, figs. 29, 30, 1899.

Lower Ordovician (Lancefieldian, Zone La 2).

Quarry, Allot. 56, Parish of Goldie, near Lancefield, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Didymograptus ensjoensis** Monsen, 1937.

*Didymograptus ensjoensis* A. Monsen, Sond. ans. Norsk. Geol. Tidssk., 16, pl. 1, fig. 40; pl. 7, figs. 12, 14, 1937. W. J. Harris and D. E. Thomas, Min. and Geol. Journ., Vic., 2 (2), p. 133, pl. 1, figs. 13*a*, 13*b*; pl. 2, figs. 15*a*, 15*b*, January, 1940.

M.U.G.D. No. 1681. COUNTERPART OF HYPOTYPE in Geol. Mus. Mines Dept. Vic. (No 43206), figured by Harris and Thomas, loc. cit., pl. 1, fig. 13*a*; pl. 2, fig. 15*a*, *b*, 1940.

Lower Ordovician (Bendigonian, Zone Be 2).

North-west corner of Allot. 30A, Sect. II., Parish of Campbelltown, Victoria.

Coll. Thos. Smith, and pres. D. E. Thomas, 1939.

**Didymograptus taylori** T. S. Hall, 1899.

*Didymograptus taylori* T. S Hall, Proc. Roy. Soc. Vic., n.s., 11 (2), p. 167, pl. 17, figs. 11, 12, February, 1899.

M.U.G.D. No. 1658. HOLOTYPE, figured by T. S. Hall, loc. cit., 1899.

Lower Ordovician (Lancefieldian, Zone La 2).

Quarry, Allot. 56, Parish of Goldie, near Lancefield, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Goniograptus (?)velatus** Harris and Thomas, 1939.

*Goniograptus velatus* W. J. Harris and D. E. Thomas, Min. and Geol. Journ., Vic., 2 (1), p. 57, text figs. 8, 9, July, 1939.

M.U.G.D. No. 1097. PARATYPE, figured by Harris and Thomas, loc. cit., text fig. 9, 1939.

Lower Ordovician (Bendigonian, Zone Be 3) .

East side of Jim Crow Creek, 100 yards north of Tipperary Spring, Daylesford, Victoria.

Coll. J. O'M. Lyons and pres. 10 11.30.

**Monograptus crinitus** Wood, 1900.

*Monograptus crinitus* E. M. R. Wood, Quart. Journ. Geol. Soc. London, 56 (2), p. 480, text figs. 23*a-d* (p 481), pl. 25, figs. 26*a*, 26*b*, May, 1900. G L Elles and E. M. R. Wood, British Graptolites, pt. 9, Mon. Pal. Soc., 66, p. 435, text figs. 298*a-c*, pl. 44, figs 3*a-c*, February, 1913. W. J. Harris and D E. Thomas, Min. and Geol. Journ., Vic., 1 (1), p. 74, pl. 2, fig. 31, July, 1937.

M.U.G.D. No. 1596. COUNTERPART OF HYPOTYPE No. 1597.

M.U.G.D. No. 1597. HYPOTYPE, figured by Harris and Thomas, loc. cit., 1937.

Upper Silurian (Melbournian).

Track to pumping station, Studley Park, Melbourne, Victoria.

Coll. E. S. Hills and pres. 1936.

**Monograptus turriculatus** (Barrande, 1850).

*Graptolithus turriculatus* Barrande, Grapt. de Bohême, p. 56, pl. 4, figs 7-11, 1850.

*Monograptus turriculatus* (Barrande): G. L Elles and E M. R. Wood, British Graptolites, pt. 9, Mon. Pal. Soc., 66, p. 438, text figs. 301*a-c*, pl. 44, figs. 4*a-e*, February, 1913. T. S. Hall, Proc. Roy. Soc. Vic., n.s., 27 (1), p. 114, pl. 17, figs. 18, 19, September, 1914.

M.U.G.D. No. 539. COUNTERPART OF HYPOTYPE No. 540.

M.U.G.D. No. 540. HYPOTYPE, figured by T. S. Hall, loc. cit., 1914.

Lower Silurian (Keilorian).

Aplin's section, the Monocline, Keilor, Victoria.

Coll. Prof. E. W. Skeats.

**Monograptus uncinatus** Tullberg var. **orbatus** Wood, 1900.

*Monograptus uncinatus* variety *orbatus* E. M. R. Wood, Quart. Journ. Geol. Soc London, 56 (2), p. 476, text figs 20*a*, 20*b*, pl. 25, figs. 23*a*, 23*b*, May, 1900. G. L. Elles and E. M. R. Wood, British Graptolites, pt. 9, Mon. Pal. Soc., 66, p. 427, text figs. 290*a*, 290*b* (p. 428), pl. 43, figs. 1*a-d*, February, 1913. W. H. Lang and I C. Cookson, Phil. Trans. Roy. Soc London, Ser. B. No. 517, vol. 224, p. 422 (citation), March, 1935. W. J. Harris and D. E. Thomas, Min. and Geol. Journ., Vic., 1 (1), p. 73, pl. 2, figs. 23-29, July, 1937.

M.U G.D., No. 1572. Hypotype, figured by Harris and Thomas, loc. cit., fig. 23, 1937.

M.U G.D. No. 1575. Counterpart of hypotype No. 1572.

Upper Silurian (Zone of *Monograptus nilssoni*).

Geol. Surv. Vic. Loc. 9, Railway Cutting, between 2¼ and 2½ miles from Alexandra, Victoria.

Obs.—This is on the slab the graptolites of which were identified by Dr. G. L. Elles in 1934 and cited by Lang and Cookson, loc. cit., 1935. The locality was erroneously cited by Harris and Thomas, loc. cit., 1937, as "19-mile Quarry, Yarra Track." (*Fide* these authors, op. cit, 2 (5), p. 305 and footnote, 1941.)

**Temnograptus magnificus** Pritchard, 1892:—**Clonograptus magnificus** (Pritchard, 1892).

*Temnograptus magnificus* G. B Pritchard, Proc. Roy. Soc. Vic., n.s., 4 (1), p. 56, pl. 6, figs. 1-3, April, 1892. Pritchard, *ibid.*, 7, p. 29, January, 1895.

*Clonograptus magnificus* Pritchard: T. S. Hall, *ibid.*, 11 (2), p. 170, February, 1899.

M.U.G.D. No. 1665. Holotype, figured by Pritchard, loc. cit., 1892.

Lower Ordovician (Lancefieldian, Zone La 2).

Quarry, Allot. 56, Parish of Goldie, near Lancefield, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

Obs.—The type specimen, measuring about one metre in diameter, is probably the largest known Victorian graptolite.

**Tetragraptus decipiens** T. S. Hall, 1899.

*Tetragraptus decipiens* T. S. Hall, Proc. Roy Soc. Vic., n.s., 11 (2), p. 168, pl. 17, figs. 13-15; pl. 18, figs. 16-19, February, 1899. R. A. Keble, Rec Geol. Surv. Vic., 4 (2), p. 199, pl. 34, 1920.

M.U.G.D. No. 1663. Paratype, figured by T. S. Hall, loc. cit., pl. 18, fig. 16, 1899.

Lower Ordovician (Lancefieldian, Zone La 2).

Quarry, Allot. 56, Parish of Goldie, near Lancefield, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

Obs.—This specimen, though referred to the above species by Hall (loc. cit., p. 178), bears six stipes and thus should be excluded from *Tetragraptus*. An accompanying specimen with five stipes (No. 1662) purchased from Dr. Pritchard, and from the same locality, was labelled "figd. T.S.H.", but apparently it was never figured by Dr. T. S. Hall.

## ANTHOZOA.

### **Acanthophyllum mansfieldense** (Dun, 1898).

*Cyathophyllum mansfieldense* W. S. Dun, Proc. Roy. Soc. Vic., n.s., 10 (2), p. 87, pl. 3, figs. 3, 4, May, 1898.

*Acanthophyllum mansfieldense* (Dun): D. Hill, *ibid.*, 51 (2), p. 223, pl. 15, figs. 1-3, July, 1939.

M.U.G.D. No 1646 HYPOTYPE, source of Fossil Section No. 610.

M.U.G.D. No. 1653. HYPOTYPE, source of Fossil Sections Nos. 608, 609.

M.U.G.D. Fossil Section Coll. No. 608. TECTOHYPOTYPE, transverse section, figured by D. Hill, loc. cit., figs. 1*a*, 1*b*, 1939, of hypotype No. 1653.

M.U.G.D. Fossil Section Coll. No. 609. TECTOHYPOTYPE, vertical section, figured by D Hill, loc. cit., fig. 2, 1939, of hypotype No. 1653.

M.U.G.D. Fossil Section Coll. No. 610 TECTOHYPOTYPE, transverse section, figured by D. Hill, loc. cit., fig. 3, 1939, of hypotype No. 1646.

This and the preceding are the basis of the description by Dr. D. Hill, loc. cit., p. 223, 1939.

Lower Devonian.

Quarry, Allot. 94, Parish of Loyola, Victoria.

Coll. Miss E. A. Ripper and pres. 27.6.33.

### **Acervularia chalkii** Chapman, 1931:—**Prismatophyllum chalkii** (Chapman, 1931).

*Acervularia chalkii* F. Chapman, Vic. Naturalist, 48 (5), p 94, text fig, September, 1931.

*Prismatophyllum chalkii* (Chapman): D. Hill, Proc. Roy. Soc. Vic, n.s., 51 (2), p. 232, pl. 13, figs. 1-5, July, 1939.

M.U.G.D. No. 1877. HOLOTYPE, figured by Chapman, *loc. cit.*, 1931, and by Hill, loc. cit., fig. 1, 1939.

Coll. A. S. Chalk, and pres. W. D. Chapman, 23.10.44.

M.U.G.D. No. 1654. HYPOTYPE, formerly Univ. Qld. Geol. Dept. No. F3252, and source of Fossil Sections Nos. 626, 627.

M U.G.D. No. 1655. HYPOTYPE, formerly Univ. Qld. Geol. Dept. No. F3253, and source of Fossil Sections Nos. 628, 629. This and the preceding are referred to by D. Hill, loc. cit., p. 233, 1939.

M.U.G.D. Fossil Section Coll. No. 626. TECTOHYPOTYPE, transverse section, figured by D. Hill, loc. cit., fig. 2, 1939, of hypotype No. 1654.

M.U.G.D. Fossil Section Coll. No. 627. TECTOHYPOTYPE, vertical section, figured by D. Hill, loc. cit., fig. 5, 1939, of hypotype No. 1654.

M.U.G.D. Fossil Section Coll. No. 628. TECTOHYPOTYPE, oblique section, figured by D. Hill, loc. cit., fig. 3, 1939, of hypotype No. 1655.

M.U.G.D. Fossil Section Coll. No. 629. TECTOHYPOTYPE, oblique section, figured by D. Hill, loc. cit., fig. 4, 1939, of hypotype No. 1655.

Lower Devonian (Yeringian).

Mitchell's Quarry, Cave Hill, Lilydale, Victoria.

Coll. Dr. D. Hill and pres. 19.4.39.

### **Columnaria (Loyolophyllum) cresswelli** Chapman, 1914.

See *Loyolophyllum cresswelli* Chapman, 1914.

**Cyathophyllum cresswelli** Chapman, 1925.

See *Mictophyllum cresswelli* (Chapman, 1925).

**Cyathophyllum elegantulum** Dun, 1898.

See *Trapezophyllum elegantulum* (Dun, 1898).

**Cyathophyllum mansfieldense** Dun, 1898.

See *Acanthophyllum mansfieldense* (Dun, 1989).

**Cyathophyllum subcaespitosum** Chapman, 1925.

See *Lyrielasma subcaespitosum* (Chapman, 1925).

" **Cystiphyllum** " sp.

"*Cystiphyllum*" sp.: D. Hill, Proc. Roy. Soc. Vic., n.s., 51 (2), p. 250, pl. 15, figs. 4, 5, 1939.

M.U G.D. No. 1652 FIGURED SPECIMEN, source of Fossil Section No. 620.

M.U.G.D. Fossil Section Coll. No. 620. FIGURED SPECIMEN, transverse section (fig. 4), and vertical section (fig. 5), figured by Hill, loc cit., 1939, of specimen No. 1652. Dr. Hill refers to the originals of figs. 4 and 5 as Nos 620A and 620B, respectively, but both are on the one slide, numbered 620.

Lower Devonian.

"Loyola" (Hill, loc. cit., p. 250, 1939) = Quarry, Allot. 94, Parish of Loyola, Victoria.

Coll. Miss E. A. Ripper, and pres. 27.6.33.

**Loyolophyllum cresswelli** (Chapman, 1914).

*Columnaria (Loyolophyllum) cresswelli* F. Chapman, Rec. Geol. Surv. Vic., 3 (3), p. 306, pl. 51, figs. 15, 16; pl. 52, figs. 17, 18, 1914.

*Loyolophyllum cresswelli* Chapman: R. Etheridge, jun., Rec. Aust. Mus., 12, p. 51, 1918. D. Hill, Proc. Roy. Soc. Vic., n.s., 51 (2), p. 242, pl. 15, figs. 8-11, 1939.

M.U.G.D. No. 1644. HYPOTYPE, source of Fossil Section No. 616.

M.U.G.D. No. 1650. HYPOTYPE, source of Fossil Section No. 618.

M.U.G.D. No. 1651. HYPOTYPE, source of Fossil Section No. 617.

M.U.G.D. Fossil Section Coll. No. 616. TECTOHYPOTYPE, transverse section, figured by Hill, loc. cit., fig. 8, 1939, of hypotype No. 1644.

M.U.G.D. Fossil Section Coll. No. 617. TECTOHYPOTYPE, oblique section, figured by Hill, loc. cit., fig. 9, 1939, of hypotype No. 1651.

M.U.G D. Fossil Section Coll. No. 618. TECTOHYPOTYPE, vertical section, figured by Hill, loc. cit., fig. 10, 1939, of hypotype No. 1650.

M.U.G.D. Fossil Section Coll. No. 619. TECTOHYPOTYPE, transverse section, figured by Hill, loc. cit., fig. 11, 1939, source unknown.

Lower Devonian.

Griffith's Quarry, Loyola, Victoria.

Coll. Miss E. A. Ripper, and pres. 27.6.33.

**Lyrielasma subcaespitosum** (Chapman, 1925).

*Cyathophyllum subcaespitosum* F. Chapman, Proc. Roy. Soc. Vic., n.s., 37 (1), p. 112, pl. 13, figs 15, 16*a*, *b*, 25th May, 1925.

*Lyrielasma subcaespitosum* (Chapman). D. Hill, *ibid.*, 51 (2), p. 244, pl. 14, figs. 1-6; pl. 15, figs. 6, 7, 1939.

M.U.G.D. Fossil Section Coll. No. 621. TECTOHYPOTYPE, transverse section, figured by Hill, loc. cit., pl. 15, fig. 6, 1939.

M.U.G.D. Fossil Section Coll. No 622 TECTOHYPOTYPE, transverse section, figured by Hill, loc. cit., pl. 15, fig. 7, 1939. The original specimen was destroyed in the making of the above slides.

Lower Devonian.

Griffith's Quarry, Loyola, Victoria.

Coll. Miss E. A. Ripper, and pres. 27.6.33.

**Mictophyllum cresswelli** (Chapman, 1925).

*Cyathophyllum cresswelli* F. Chapman, Proc Roy. Soc. Vic, n.s, 37 (1), p. 111, pl. 13, figs 11-14, May, 1925

*Mictophyllum cresswelli* (Chapman) D. Hill, *ibid*, 51 (2), p. 246, pl. 14, figs. 7-11, July, 1939.

M.U.G.D. Fossil Section Coll. No. 630 TECTOHYPOTYPE, vertical section, figured by D Hill, loc. cit., fig. 9, 1939, of Univ. Qld. Geol. Dept. No. F3289.

Lower Devonian (Yeringian).

Mitchell's Quarry, Cave Hill, Lilydale, Victoria.

Coll. Dr. D. Hill and pres. 19.4.39

**Phillipsastraea speciosa** Chapman, 1914.

*Phillipsastraea speciosa* F. Chapman, Rec. Geol. Surv. Vic, 3 (3), p. 306, pl. 49, figs 10, 11, pl. 50, figs. 12-14, 1914 D. Hill, Proc. Roy. Soc. Vic., n.s., 51 (2), p. 237, pl. 16, figs. 1-4, 1939

M.U.G.D No. 1648. HYPOTYPE, source of Fossil Section No. 612.

M.U.G.D. No. 1649. HYPOTYPE, source of Fossil Section No. 611.

M.U.G.D. Fossil Section Coll. No. 611. TECTOHYPOTYPE, transverse and part of a vertical section, figured by Hill, loc. cit., fig. 3, 1939, of hypotype No. 1649.

M.U.G.D. Fossil Section Coll. No. 612. TECTOHYPOTYPE, vertical section, figured by Hill, loc. cit., fig. 4, 1939, of hypotype No. 1648.

Lower Devonian.

Loyola, Victoria.

Coll. Miss E. A. Ripper, and pres. 27.6.33.

**Pleurodictyum megastomum** Dun, 1898.

*Pleurodictyum problematicum* Goldfuss?: A. F. Foerste, Bull. Sci. Lab. Denison Univ, 3 (2), p. 132, pl. 13, fig. 22, 1888. Not *Pleurodictyum problematicum* G. A. Goldfuss, Petref. Germ., 1 (2), p. 113, pl. 43, figs. 18*a-g*, 1829.

*Pleurodictyum*, sp. (?*P. megastomum*, McCoy, MS.): W. S. Dun, Proc. Roy. Soc. Vic., n.s., 10 (2), p. 83, pl. 3, fig. 1, May, 1898.

*Pleurodictyum megastomum* Dun: F. Chapman, *ibid.*, 15 (2), p. 105, pl 16, figs. 2-5, 1903. F. Chapman, *ibid.*, 33, p. 216, pl. 9, figs. 4-6, 1921. R. S. Allan, Trans. N.Z. Inst., 60 (2), p. 322, 1929. R. B. Withers, Proc. Roy. Soc. Vic., n.s., 44 (1), p. 15, text figs. 1-6, 1932. J. Shirley, Quart. Journ. Geol. Soc. Lond., 94 (4), p. 463, pl. 40, figs. 5-8, 1938. E. D. Gill, Proc. Roy. Soc. Vic., n.s., 54 (1), p. 35, pl. 4, figs. 1, 3, 4, 6, 9, 1942.

M.U.G.D. No. 1711. HYPOTYPE, mould of corallites, figured by Gill, loc. cit., fig. 1, 1942.

M.U.G.D. No. 1712. Hypotype, epitheca on *Spirifer*, counterpart of No. 1711, figured by Gill, loc. cit., fig. 3, 1942.

Lower Devonian (Yeringian).

North of Lilydale, Victoria. E. D. Gill's Locality No. 3 (Proc. Roy. Soc. Vic., n.s., 52 (2), pp. 252, 258, 1940).

Pres. Rev. E. D. Gill, 24.5.41.

M.U.G.D. No 1713. Hypotype, mould of corallites, nineteen-celled form, figured by Gill, loc. cit., fig 4, 1942.

M.U.G.D. No. 1714. Hypotype, three-celled form, figured by Gill, loc. cit., fig 6, 1942.

Lower Devonian (Yeringian).

Syme's Tunnel, Killara, Victoria.

Pres. Rev. E. D. Gill, 24.5.41.

**Prismatophyllum chalkii** (Chapman, 1931).

See *Acervularia chalkii* Chapman, 1931.

**Prismatophyllum stevensi** (Chapman, 1925).

See *Spongophyllum stevensi* Chapman, 1925

**Rugose Coral**, gen. et. sp. indet.

Gen. et sp. indet.: D. Hill, Proc. Roy. Soc. Vic., n.s., 51 (2), p. 256, pl 15, fig. 12, 1939.

M.U.G.D. Fossil Section Coll. No. 623. Figured specimen, oblique section, figured by Hill, loc. cit, 1939. The original specimen was destroyed in the process of making the slide.

Lower Devonian.

Loyola, Victoria.

Coll. Miss E. A. Ripper, and pres. 27.6.33.

**Spongophyllum stevensi** Chapman, 1925:—**Prismatophyllum stevensi** (Chapman, 1925).

*Spongophyllum stevensi* F. Chapman, Proc. Roy. Soc. Vic., n.s., 37 (1), p. 113, pl. 14, figs. 17*a*, 17*b*; pl. 15, figs. 24, 27, May, 1925. O. A. Jones, Proc. Roy. Soc. Qld., 44, p. 52, March, 1933.

*Prismatophyllum stevensi* (Chapman): D. Hill, Proc. Roy. Soc. Vic., n.s., 51 (2), p. 231, pl. 13, figs. 6, 7, July, 1939.

M.U.G.D. No. 797. Portion of holotype in National Museum, Melbourne (No. 13305), figured by Chapman, loc. cit., 1925.

M.U.G.D. No. 797A. Polished piece cut from No. 797.

M.U.G.D. No. 797B. Transverse slice cut from holotype.

M.U.G.D. Fossil Section Coll. No. 624. Tectohypotype, vertical section of holotype, cut from No. 797A, and figured by D. Hill, loc. cit., fig. 6, 1939.

M.U.G.D. Fossil Section Coll. No. 625. Tectohypotype, transverse section of holotype, cut from No. 797A, and figured by D. Hill, loc. cit., fig. 7, 1939.

Lower Devonian (Yeringian).

Mitchell's Quarry, Cave Hill, Lilydale, Victoria.

Pres. L. E. Stevens, 8.8.21.

**Trapezophyllum elegantulum** (Dun, 1898).

*Cyathophyllum elegantulum* W. S. Dun, Proc. Roy. Soc. Vic., n.s., 10 (2), p. 85, pl. 3, figs. 5, 6, May, 1898.

*Cyathophyllum? elegantulum* Dun: R. Etheridge, jun., Prog. Rept. Geol. Surv. Vic., 11, p. 31, pl. B, figs. 2-4, 1899.

*Cyathophyllum* (*Trapezophyllum*) *elegantulum* Dun: R. Etheridge, jun., *ibid.*, p. 32, 1899.

*Trapezophyllum elegantulum* (Dun): D. Hill, Proc. Roy. Soc. Vic, n.s., 51 (2), p. 235, pl. 16, figs. 9-11, 1939.

M.U.G.D. No. 1647. HYPOTYPE, source of Fossil Sections Nos. 613, 614.

M.U.G.D. Fossil Section Coll. No. 613. TECTOHYPOTYPE, transverse section, figured by Hill, loc. cit., fig. 9, 1939, of hypotype No. 1647.

M.U.G.D. Fossil Section Coll. No. 614. TECTOHYPOTYPE, vertical section, figured by Hill, loc. cit., fig. 10, 1939, of hypotype No. 1647.

M.U.G.D. Fossil Section Coll. No. 615. TECTOHYPOTYPE, vertical section, figured by Hill, loc. cit., fig. 11, 1939. No specimen is known from which this slide was prepared.

Lower Devonian.

Loyola, Victoria.

Coll. Miss E. A. Ripper, and pres. 27.6.33.

## ASTEROIDEA.

**Eospondylus tenuis** Withers and Keble, 1934.

*Eospondylus tenuis* R. B. Withers and R. A. Keble, Proc. Roy. Soc. Vic., n.s., 47 (1), p. 206, pl. 11, fig. 7 and text fig. 12 on p. 211. 22nd December, 1934.

M.U.G.D No. 1497. HOLOTYPE, oral aspect, figured by Withers and Keble, loc. cit., 1934.

"Silurian (Yarravian Series)" (Withers and Keble, loc. cit., p. 207, 1934) = Upper Silurian (Melbournian).

"Moonee Ponds" (Withers and Keble, loc. cit., p. 207, 1934) = Cliff section, N. of Brunswick Road bridge, Moonee Ponds Creek, West Brunswick, Victoria.

Collected by E. S. Hills, 1926.

**Furcaster bakeri** Withers and Keble, 1934.

*Furcaster bakeri* R. B. Withers and R. A. Keble, Proc. Roy. Soc. Vic., n.s., 47 (1), p. 204, pl. 11, figs. 9, 10 and text figs. 10, 11 on p. 211, 22nd December, 1934.

M.U.G.D. No. 1498. SYNTYPE, oral aspect, figured by Withers and Keble, loc. cit., fig. 9 and text fig. 10, 1934.

M.U.G.D. No. 1499 SYNTYPE, aboral aspect (counterpart of No. 1498) figured by Withers and Keble, loc. cit., fig. 10 and text fig. 11, 1934.

"Silurian (Yarravian)" (Withers and Keble, loc. cit., p. 205, 1934) = Upper Silurian (Melbournian).

East side of new Yarra Boulevard, vicinity of Dight's Falls, Studley Park, Victoria. The specimen was not *in situ*.

Collected by G. Baker, 27.1.34.

**Hallaster parvus** Withers and Keble, 1934.

*Taeniaster* (?) aff *spinosus* Billings E. S. Hills, Proc. Roy. Soc. Vic., n.s., 41 (2), p. 179, 1929 (list name). Not *Taeniaster spinosus* E. Billings, Geol. Surv. Canada, Canadian Organic Remains, decade 3, p. 81, pl. 10, figs 3*a-d*, 1858

*Hallaster parvus* R B Withers and R A. Keble, Proc. Roy. Soc Vic, n.s., 47 (1), p. 203, pl. 11, figs. 5, 6, text figs. 8, 9 on p. 211, 22nd December, 1934.

M.U.G.D. No. 792. SYNTYPE, oral aspect, figured by Withers and Keble, loc. cit., fig. 5 and text fig. 8, 1934.

M.U.G.D. No. 793. SYNTYPE, aboral aspect (counterpart of No. 792), figured by Withers and Keble, loc. cit., fig. 6 and text fig. 9, 1934.

Silurian.

Blue Hills, Taggerty, Victoria

Presented by E. S. Hills, 20.2.29.

**Lapworthura pulcherrima** Withers and Keble, 1934.

*Lapworthura pulcherrima* R. B. Withers and R. A. Keble, Proc. Roy. Soc. Vic, n.s., 47 (1), p. 201, pl. 11, figs. 1, 2 and text figs. 4, 5 on p. 201, 22nd December, 1934.

M.U.G.D. No. 1157. SYNTYPE, aboral aspect, figured by Withers and Keble, loc. cit., fig. 1 and text fig. 4, 1934.

M.U.G.D. No. 1500. SYNTYPE, oral aspect (counterpart of No. 1157), figured by Withers and Keble, loc. cit., fig. 2 and text fig. 5, 1934.

"Silurian (Yarravian Series)" (Withers and Keble, loc. cit., p. 202, 1934) = Upper Silurian (Melbournian).

"Dawson-street, West Brunswick, about quarter of a mile north of the Geological Survey of Victoria Locality Flemington (B8)" (Withers and Keble, loc. cit, p. 202, 1934), Victoria. The specimen came from a sewerage tunnel on the east side of Moonee Ponds Creek (D. McCance, personal communication).

Presented by D. M. McCance, July, 1927.

## ECHINOIDEA.

**Linthia mooraboolensis** Pritchard, 1908.

*Linthia mooraboolensis* G. B. Pritchard, Proc. Roy Soc. Vic., n.s., 21 (1), p. 394, pl. 22, figs. 1, 2; pl. 23, figs. 3, 4, August, 1908.

M.U.G.D. No. 1689. HOLOTYPE, figured by Pritchard, loc. cit., 1908.

Miocene (Batesfordian).

Filter Quarries (limestones), Moorabool River near Batesford, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

cf. **Lovenia** sp.

cf. *Lovenia* F. Chapman, Vic. Naturalist, 39 (11), p. 158, pl. 4, 2 figs, 8th March, 1923

M.U.G.D. No. 555. FIGURED SPECIMEN, internal cast, figured by Chapman, loc. cit., 1923.

Lower Pliocene (Kalimnan?).

Sand-pit, Studley Park, Kew, Victoria.

Collected on geological excursion of Melbourne University students, 1917.

## BRACHIOPODA.

### **Anoplia australis** Gill, 1942.

*Anoplia australis* E. D. Gill, Proc. Roy. Soc. Vic., n.s., 54 (1), p. 38, pl. 4, fig. 8, 15th April, 1942.

M.U.G.D. No. 1720 HOLOTYPE, internal casts of dorsal and ventral valves, figured by Gill, loc. cit., 1942.

Lower Devonian (Yeringian).

Quarry in impure limestone, south side of Warburton highway, Seville, Victoria. Military Survey of Victoria, Ringwood Sheet, reference 497, 413.

Pres. Rev. E. D. Gill, 24.5.41.

### **Anoplia withersi** Gill, 1942.

*Anoplia withersi* E D. Gill, Proc. Roy. Soc. Vic., n.s., 54 (1), p. 39, pl. 4, fig. 7, 15th April, 1942.

M U.G D. No. 1721. HOLOTYPE, internal cast of ventral valve, figured by Gill, loc cit., 1942.

Lower Devonian (Yeringian).

Syme's Tunnel, Killara, Victoria.

Pres. Rev. E. D. Gill, 24 5 41.

### **Chonetes bipartita** Chapman, 1913.

See *Stropheodonta bipartita* (Chapman, 1913).

### **Cyrtinopsis perlamellosus** (J. Hall, 1857).

*Spirifer perlamellosa* J. Hall, Tenth Ann. Rept. New York State, Cabinet Nat. Hist., p 57, figs 1, 2, 1857

*Spirifer perlamellosus* J. Hall, Nat. Hist. New York, Palaeont, 3, p. 201, pl. 26, figs. 1*a-s*, 2*a-g*, 1859. J. Hall and J. M. Clarke, Nat. Hist. New York, pt 6, Palaeont., 8 (2), p. 15, pl. 35, figs. 7-13, 1894.

*Spirifer (Delthyris) perlamellosus* Hall: A. W. Grabau and H. W. Shimer, North American Index Fossils, 1, p. 320, text fig. 407 (p. 321), 1909.

*Cyrtinopsis perlamellosus* (Hall): J. Shirley, Quart Journ. Geol. Soc. Lond., 94 (4), p. 482, pl. 44, figs. 9, 10, 1938. E. D. Gill, Proc. Roy. Soc. Vic., n s., 54 (1), p 42, pl. 6, figs. 6, 7, 1942.

M U.G D. No. 1722. HYPOTYPE, external mould of dorsal valve, figured by Gill, loc. cit., fig. 6, 1942.

M.U.G.D. No. 1723. HYPOTYPE, internal cast of ventral valve, figured by Gill, loc. cit., fig. 7, 1942.

Lower Devonian (Yeringian).

Hull Road, Mooroolbark, Victoria. E. D. Gill's Locality No. 13 (Proc. Roy Soc. Vic, n.s., 52 (2), pp. 252 et seq., 1940).

Pres. Rev. E. D. Gill, 24.5.41.

### **Eospirifer densilineata** (Chapman, 1908).

*Spirifer perlamellosus* J. Hall variety *densilineata* F. Chapman, Proc. Roy. Soc. Vic., n.s., 21 (1), p. 223, pl. 4, figs. 1, 2; pl. 5, August, 1908.

*Eospirifer densilineata* (Chapman): E. D. Gill, *ibid.*, 54 (1), p. 43, pl. 4, fig. 2, 1942.

M.U.G.D. No. 1715. HYPOTYPE, figured by Gill, loc. cit., 1942.

Lower Devonian (Yeringian).

Cemetery Hill Road, Whittlesea, Victoria (type locality). J. T. Jutson's Locality VII. (Proc. Roy. Soc. Vic., n.s., 21 (1), p. 213, pl. 3, 1908).

Pres. Rev. E. D. Gill, 24.5.41.

**Fascicostella gervillei** (Defrance, 1827).

*Strophomenes gervillei* M J L. Defrance, Dict Sci nat., 32, 51, p. 152, 1827.
*Orthis gervillei* Defrance J Barrande, Haidinger, Naturwiss Abh II, 1 Abth., p 48, pl 19, fig. 10, 1848. J. Barrande, Syst. sil Bohême, 5, pl. 58, figs. 10*a-e;* pl 60, fig II, 1A, 2*c*, 3*a*, 4*e*, pl. 126, fig. II, 3*a*, *b*, 4*c*, 1879. C. Barrois, Mém Soc. Géol. Nord, 2 (1), p 237, pl 9, fig 1, 1882. D. P Oehlert. Ann Sci géol., 19, p 44, pl. 4, figs 45-55, 1886. P. Assmann, Jahrb K preuss. geol Landesanst., 31 (1), p 161, pl 10, fig 3, 1910. F. Herrmann, *ibid*, 33 (1), p 349, pl 21, figs. 4, 5, 1912. T Huffner, *ibid*, 37 (1), p 291. W. Paeckelmann, Abh preuss. geol Landesanst N. F 98, p. 116, 1925. R Kozlowski, Palaeont. Polonica, 1, p. 70, pl. 1, fig. 32, 1929
*Dalmanella gervillei* Defrance W. Paeckelmann and H Sieverts, Abh preuss. geol Landesanst N F 142, p 31, 1932
*Fascicostella gervillei* Defrance: C Schuchert and G. A Cooper, Amer. Journ Sci, [5] 22, p. 246, 1931. C. Schuchert and G. A. Cooper. Mem. Peabody Mus. Nat. Hist, 4, p 129, pl 92, figs 12, 15, 1932. J Shirley, Quart. Journ Geol Soc Lond, 94 (4), p 466, pl 41, figs 4-6, 1938 E. D. Gill, Proc Roy Soc. Vic, n.s., 54 (1), p. 37, pl 6, figs 3-5, 1942.

M.U.G.D. No. 1728. HYPOTYPE, internal cast of ventral valve, figured by Gill, loc. cit, fig 3, 1942.

M U.G.D. No. 1729. HYPOTYPE, internal cast of ventral valve, figured by Gill, loc. cit., fig. 4, 1942.

M.U.G.D. No 1730. HYPOTYPE, internal cast of dorsal valve, figured by Gill, loc. cit., fig 5, 1942.

Lower Devonian (Yeringian)

Melbourne Hill, Lilydale, Victoria E D. Gill's Locality No. 7 (Proc. Roy. Soc. Vic., n.s., 52 (2), pp. 252, 259, 1940).

Pres. Rev E. D. Gill, 24 5.41.

**Hipparionyx minor** Clarke, 1909.

*Hipparionyx minor* J. M. Clarke, Mem New York State Mus., 9 (2), p. 124, pl. 31, figs. 16-20, 1909. J. Shirley, Quart Journ. Geol. Soc. Lond., 94 (4), p. 472, pl. 42, figs. 1-6, 1938 E. D. Gill, Proc Roy. Soc Vic, n s., 54 (1), p. 39, pl. 5, figs. 1, 10; pl. 6, fig. 2, 1942

M.U.G D. No. 1731. HYPOTYPE, internal cast of ventral valve, figured by Gill, loc. cit., fig. 1, 1942.

M.U.G.D No. 1732. HYPOTYPE, external mould of ventral valve, counterpart of No 1731, figured by Gill, loc. cit., fig. 10, 1942

Lower Devonian (Yeringian).

Hull Road, Mooroolbark, Victoria. E. D. Gill's Locality No. 13 (Proc. Roy. Soc. Vic., n.s., 52 (2), pp. 252 et seq, 1940).

Pres. Rev. E. D. Gill, 24.5.41.

**Leptaena rhomboidalis** (Wilckens, 1769).

*Conchita rhomboidalis* C. F. Wilckens, Nachr Selt. Verst, p. 77, pl 8, figs. 43, 44, 1769.
*Strophomena rhomboidalis* Wilckens sp: J Barrande, Syst. sil. Bohême, 5, p. 197, pl. 41, figs. 25*a-c*, 30*a*, *b*, 1879.
*Leptaena rhomboidalis* (Wilckens): J. Hall and J. M. Clarke, Nat. Hist New York, pt. 6, Palaeont., 8 (1), pl. 8, figs. 20-27, 1892. A. W Grabau and H. W. Shimer, North American Index Fossils, 1, p. 226, text-fig. 273*b*, 1909.
*Leptaena* (*Leptagonia*) *rhomboidalis* (Wilckens): F. McCoy, Prodromus Palaeont. Vic. Decade 5, p 19, pl. 46, fig. 1, 1877.
[?] *Leptaena rhomboidalis* Wilckens sp.: F. Chapman, Proc. Roy. Soc. Vic., n s., 26 (1), pp. 101, 102, pl. 10, fig. 3 (*non* p. 103, pl. 10, figs. 4-7), 1913.
*Leptaena rhomboidalis* (Wilckens): E. D. Gill, *ibid.*, 54 (1), p. 40, pl. 5, figs. 5, 8, 1942.

M.U.G.D. No. 1718. HYPOTYPE, internal mould of dorsal valve, figured by Gill, loc. cit., fig. 3, 1942.

M.U.G.D. No. 1719. HYPOTYPE, external cast, counterpart of No. 1718, figured by Gill, loc. cit., fig. 8, 1942.

Lower Devonian (Yeringian)

Hull Road, Mooroolbark, Victoria E. D. Gill's Locality No. 13 (Proc. Roy. Soc Vic., n s., 52 (2), pp. 252 et seq., 1940).

Pres. Rev. E. D Gill, 24 5.41.

## Nucleospira cf. marginata Maurer, 1886.

*Nucleospira marginata* F. Maurer, Die Fauna des rechtsrheinischen Unterdevon, Darmstadt, p. 19, 1886. L. Beushausen, Jahrb K. preuss. geol. Landesanst., 17, p. 289, pl. 5, figs. 8-12, 1897.

*Nucleospira* cf *marginata* Maurer. J. Shirley, Quart. Journ. Geol. Soc Lond., 94 (4), p 481, pl. 94, figs. 6-8, 1938. E. D Gill, Proc. Roy. Soc Vic., n.s., 54 (1), p. 43, pl. 4, fig 5, pl. 5, fig. 6, 1942.

M.U.G.D. No 1726. HYPOTYPE, internal cast of ventral valve, figured by Gill, loc. cit, pl. 4, fig. 5, 1942.

M.U.G D No 1727. HYPOTYPE, internal cast of ventral valve, figured by Gill, loc. cit, pl. 5, fig. 6, 1942.

Lower Devonian (Yeringian).

Hull Road, Mooroolbark, Victoria. E. D. Gill's Locality No. 13 (Proc. Roy. Soc. Vic., n.s., 52 (2), pp. 252 et. seq., 1940).

Pres. Rev. E. D. Gill, 24.5 41.

## Schizophoria provulvaria (Maurer, 1893).

*Orthis provulvaria* F. Maurer, Neues Jahrb. f. Min., 1, p. 7, pl. 3, figs. 1-4, 1893.

*Schizophoria provulvaria* (Maurer). F. Drevermann, Palaeontographica, 1, p. 267, pl. 30, figs 29, 30, 1904. C. Schuchert and G A. Cooper, Mem. Peabody Mus Nat. Hist., 4 (1), pl. 23, fig. 11, 1932. E. Maillieux, Mém. Mus roy Hist. nat. Belg, 23, p. 53, 1936 J. Shirley, Quart. Journ. Geol. Soc Lond., 94 (4), p 465, pl 40, figs. 10-13, 1938 E D. Gill, Proc Roy. Soc. Vic, n s., 54 (1), p. 63, pl. 6, fig. 1, 1942.

M.U.G.D. No. 1733. HYPOTYPE, internal cast of ventral valve, figured by Gill, loc. cit., 1942

Lower Devonian (Yeringian).

Hull Road, Mooroolbark, Victoria. E. D. Gill's Locality No. 13 (Proc. Roy. Soc. Vic., n.s., 52 (2), pp. 252 et. seq., 1940).

Pres. Rev. E. D. Gill, 24.5.41.

## (?) Siphonotreta lancefieldiensis Sherrard, 1930.

(?) *Siphonotreta lancefieldiensis* K. Sherrard, Proc. Roy. Soc. Vic., n.s., 42 (2), p. 137, pl. 11, fig 4, 13th March, 1930.

M U.G.D. No. 995. HOLOTYPE, figured by Sherrard, loc. cit., 1930.

Lower Ordovician (Lancefieldian, Zone La 2).

Quarry, Allot. 56, Parish of Goldie, near Lancefield, Victoria.

Coll. Sept., 1923 and pres. Mrs. K. Sherrard, 12.12.29.

## Spirifer perlamellosus J. Hall, 1857.

See *Cyrtinopsis perlamellosus* (J. Hall, 1857).

**Spirifer perlamellosus** J. Hall var. **densilineata** Chapman, 1908.

See *Eospirifer densilineata* (Chapman, 1908).

**Stropheodonta bipartita** (Chapman, 1913).

*Chonetes bipartita* F. Chapman, Proc. Roy. Soc. Vic, n.s., 26 (1), p. 104, pl. 10, figs. 8-10, September, 1913.

*Stropheodonta bipartita* (Chapman): E. D Gill, *ibid*, 54 (1), p. 41, pl. 5, figs. 7, 9; pl 6, fig 10, 1942

M.U.G.D. No. 1724. Hypotype, external moulds of both valves, figured by Gill, loc. cit., pl. 5, fig. 9; pl. 6, fig. 10, 1942.

M.U G.D. No. 1725. Hypotype, internal casts of both valves, counterpart of No. 1724, figured by Gill, loc. cit., pl. 5, fig. 7, 1942.

Lower Devonian (Yeringian).

Yellingbo, Victoria. " . . . a low cutting on the road running west from the picnic ground beside Woori Yallock Creek, about a quarter of a mile from the creek" (Gill, loc. cit., p. 26, 1942).

Pres. Rev. E. D. Gill, 24 5.41.

## PELECYPODA.

**Antigona (Proxichione) cognata** (Pritchard, 1903).

See *Chione cognata* Pritchard, 1903.

**Antigona (Proxichione) etheridgei** (Pritchard, 1903).

See *Chione etheridgei* Pritchard, 1903.

**Arca capulopsis** Pritchard, 1901.

*Arca capulopsis* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 14 (1), p. 23, pl. 2, figs. 1, 2, August, 1901.

M.U.G.D. No. 1773. Holotype, left valve, figured by Pritchard, loc. cit., 1901.

Miocene (Balcombian).

Orphanage Hill, Fyansford, near Geelong, Victoria.

Coll. T. S. Hall. Purchased from Dr. G. B. Pritchard, 11.10.39.

**Aulacomya mooraboolensis** (Pritchard, 1903).

See *Mytilus mooraboolensis* Pritchard, 1903.

**Cardita excrescens** Pritchard, 1903:—**Venericardia excrescens** (Pritchard, 1903).

*Cardita excrescens* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 15 (2), p. 98, pl. 12, figs. 2, 3, February, 1903.

M.U.G D. No. 1753. Holotype, left valve, figured by Pritchard, loc. cit., 1903.

Miocene (Balcombian).

Shores of Lake Bullen Merri, near Camperdown, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Cardita maudensis** Pritchard, 1895:—**Venericardia maudensis** (Pritchard, 1895).

*Cardita maudensis* G. B Pritchard, Proc. Roy Soc Vic, n s., 7, p. 229, pl 12, figs. 6, 7, January, 1895. G. F Harris, Cat. Tert. Moll Brit. Mus., pt. 1, p. 360, 1897.

M U.G.D. No. 1745. SYNTYPE, right valve, figured by Pritchard, loc. cit, fig. 6, 1895.

M.U.G.D. No. 1746. SYNTYPE, left valve, figured by Pritchard, loc. cit., fig. 7, 1895.

Miocene (Janjukian?).

"Lower Eocene calcareous sands, Moorabool Valley near Maude" (Pritchard, 1895) = Lower beds, Maude, Victoria

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Carditella regularis** Pritchard, 1901.

*Carditella regularis* G B Pritchard, Proc Roy. Soc. Vic, n s, 14 (1), p 28, pl. 2, fig. 5, August, 1901

M.U.G.D. No. 1775. HOLOTYPE, right valve, figured by Pritchard, loc. cit., 1901.

Grice's Creek, between Frankston and Mornington, Port Phillip, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Chione cognata** Pritchard, 1903:—**Antigona (Proxichione) cognata** (Pritchard, 1903).

*Chione cognata* G. B. Pritchard, Proc. Roy. Soc Vic, n.s., 15 (2), p. 101, pl. 12, fig 5, February, 1903.

M.U G.D. No. 1755. HOLOTYPE, left valve, figured by Pritchard, loc. cit., 1903.

Lower Pliocene (Kalimnan).

Grange Burn, below Forsyth's, near Hamilton, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Chione etheridgei** Pritchard, 1903:—**Antigona (Proxichione) etheridgei** (Pritchard, 1903).

*Chione etheridgei* G B Pritchard, Proc Roy Soc Vic, n.s., 15 (2), p. 99, pl. 12, fig. 1, February, 1903

M.U.G D. No. 1752. HOLOTYPE, left valve, figured by Pritchard, loc. cit, 1903.

Miocene (Janjukian).

"Lower beds of the Spring Creek series or Bird Rock Bluff, near Geelong" (Pritchard, loc. cit., p. 100, 1903) = Lower beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Chione halli** Pritchard, 1895.

*Chione halli* G. B. Pritchard, Proc. Roy. Soc Vic., n.s., 7, p. 229, pl. 12, figs. 10-12, January, 1895. Not *Chione hallii* R. Tate, Trans. Roy. Soc. S. Aust., 24 (2), p. 107, pl. 2, fig. 5, 1901 (= *Chione roberti* G. B. Pritchard, nom. mut., Vic. Naturalist, 23 (6), p. 117, 4th October, 1906.)

M.U.G.D. No. 1749. SYNTYPE, right valve, figured by Pritchard, loc. cit., fig. 10, 1895.

M U.G.D. No. 1750. SYNTYPE, left valve, figured by Pritchard, loc. cit., fig. 11, 1895.

M.U.G.D. No. 1751. SYNTYPE, right valve, figured by Pritchard, loc. cit., fig 12, 1895.

Miocene (Janjukian).

"Lower Eocene sands and clays of Spring Creek, 14 miles south of Geelong" (Pritchard, 1895) = Lower beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Chlamys asperrimus asperrimus** (Lamarck, 1819).

*Pecten asperrimus* J. P B A Lamarck, Hist Nat Anim. s. Vert, 11, p. 174, 1819 B Delessert, Rec. Coq. décr. par Lamarck dans son Hist. Nat. Anim. s Vert. et non encore figurées, pl 15, figs. 1*a*, 1*b*, 1841.

*Chlamys apserrimus asperrimus* (Lamarck, 1819) J. H Gatliff and F A Singleton, Proc. Roy Soc. Vic, n.s, 42 (2), p. 73, pl 2, figs 1, 2; pl 3, fig. 5; pl 4, fig 10, March, 1930.

M U G.D. No. 989. HYPOTYPE, figured by Gatliff and Singleton, loc. cit., pl. 2, fig. 1; pl 4, fig 11, 1930.

M.U.G.D No. 990 HYPOTYPE, counterpart of No. 989, figured by Gatliff and Singleton, loc. cit., pl. 3, fig. 5, 1930

M.U.G.D No. 991. HYPOTYPE, figured by Gatliff and Singleton, loc. cit, pl 2, fig 2, 1930.

M.U G.D. No. 992. COUNTERPART OF HYPOTYPE No. 991.

Recent.

Westernport, Victoria (dredged).

Pres. J. H. Gatliff, 8 8.29.

**Crassatellites camurus** Pritchard, 1903:—**Eucrassatella camura** (Pritchard, 1903).

*Crassatellites camurus* G B. Pritchard, Proc. Roy Soc Vic, n s., 15 (2), p. 96, pl. 14, figs. 5-9, February, 1903.

M.U.G.D. No. 1761. SYNTYPE, left valve, figured by Pritchard, loc. cit., fig 5, 1903.

M.U.G.D. No. 1762. SYNTYPE, right valve, figured by Pritchard, loc cit., fig 6, 1903

Lower Pliocene (Kalimnan).

Grange Burn, between Forsyth's and Henty's, near Hamilton, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

M.U.G.D. No. 1763. SYNTYPE, juvenile left valve, figured by Pritchard, loc. cit., fig. 7, 1903.

M.U.G.D. No. 1764. SYNTYPE, juvenile right valve, figured by Pritchard, loc. cit., fig. 8, 1903.

M.U.G.D. No. 1765. SYNTYPE, juvenile right valve, figured by Pritchard. loc. cit., fig. 9, 1903.

M.U.G.D. No. 1766. SYNTYPE, juvenile left valve, unfigured.

Lower Pliocene (Kalimnan).

"Muddy Creek, near the State School" (Pritchard, loc. cit., p. 97, 1903) = MacDonald's, Muddy Creek, near Hamilton, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

The above shells (Nos. 1761-6) were in a box with a label in Pritchard's handwriting, "Crassatellites camarus [*sic*] Pritchard. *Types.* Miocene. Grange Burn and Muddy Creek, W. Vic." They have been allocated to the above localities upon their mode of preservation.

**Crassatellites kingicoloides** Pritchard, 1903:—**Eucrassatella kingicoloides** (Pritchard, 1903).

*Crassatellites kingicoloides* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 15 (2), p. 94, pl. 13, figs. 1-3, February, 1903.

M.U.G.D. No. 1756. HOLOTYPE, paired valves, figured by Pritchard, loc. cit., 1903.

Lower Pliocene (Kalimnan).

Jimmy's Point [= Jemmy's Point], Kalimna, Gippsland Lakes, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Crassatellites maudensis** Pritchard, 1903:—**Eucrassatella maudensis** (Pritchard, 1903).

*Crassatellites maudensis* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 15 (2), p. 93, pl. 14, figs. 2, 3, February, 1903.

M.U.G.D. No. 1758. SYNTYPE, right valve, figured by Pritchard, loc. cit., fig. 2, 1903.

M.U.G.D. No. 1759. SYNTYPE, right valve, figured by Pritchard, loc. cit., fig. 3, 1903.

Miocene (Janjukian).

"Lower and Middle beds of the Spring Creek series, or Bird Rock Bluff, near Geelong" (Pritchard, loc. cit., p. 94, 1903) = Bird Rock cliffs, near Spring Creek, Torquay, Victoria. The inner lid of box bears "Spring Creek" only.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Cucullaea corioensis praelonga** Singleton, 1932:—**Cucullaea praelonga** (Singleton, 1932).

*Cucullaea corioensis* F. McCoy, Prodromus Palaeont. Vic., decade 3, pl. 27, figs. 3(?), 5*a* (*non* 4, 5), 1876.

*Cucullaea corioensis praelonga* F. A. Singleton, Proc. Roy. Soc. Vic., n.s., 44 (2), p. 303, pl. 26, figs. 20*a*, *b*, 20th April, 1932.

M.U.G.D. No. 1320. HOLOTYPE, right valve, figured by Singleton, loc. cit., 1932.

Lower Pliocene (Kalimnan).

"Forsyth's," Grange Burn, near Hamilton, Victoria.

Coll. H. S. Summers. Presented by F. A. Singleton, 29.2.32. It was formerly No. 5 in F. A. Singleton's private collection.

**Cucullaea praelonga** (Singleton, 1932).

See *Cucullaea corioensis praelonga* Singleton, 1932.

**Cucullaea (Cucullona) psephea** Singleton, 1943.

*Cucullaea* (*Cucullona*) *psephea* F. A. Singleton, Proc. Roy. Soc. Vic., n.s., 55 (2), p. 270, pl. 13, figs. 7*a*, *b*, 8*a*, *b*, October, 1943.

M.U.G.D. No. 1869. HOLOTYPE, right valve, figured by Singleton, loc. cit., fig. 7*a*, *b*, 1943.

M.U.G.D. No. 1870. PARATYPE, right valve, figured by Singleton, loc. cit., fig. 8*a*, *b*, 1943.

Eocene.

Second point north-west of Pebble Point, coastal cliffs 2½ miles south-east of Princetown, Victoria.

Coll. Jan., 1942, and pres. G. Baker, Jan., 1943.

**Dosinia densilineata** Pritchard, 1896.

*Dosinia densilineata* G. B. Pritchard, Proc. Roy. Soc Vic., n.s., 8, p 135, pl. 4, figs. 5-7, April, 1896.

M.U.G.D. No. 1738. Syntype, left valve, figured by Pritchard, loc. cit., fig. 5, 1896.

M.U.G.D. No. 1739. Syntype, paired valves, figured by Pritchard, loc. cit., fig. 6, 1896.

M U.G.D. No. 1740. Syntype, right valve, figured by Pritchard, loc. cit., fig. 7, 1896.

Miocene (Janjukian).

"Lower Eocene sandy beds of Spring Creek, near Geelong" (Pritchard, loc. cit, p. 137, 1896) = Lower beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Eotrigonia intersitans** (Tate, 1896).

See *Trigonia tatei* Pritchard, 1895.

**Eotrigonia lutosa** (Pritchard, 1903).

See *Trigonia semiundulata* Jenkins var *lutosa* Pritchard, 1903.

**Eotrigonia semiundulata** (Jenkins, 1865).

See *Trigonia semiundulata* Jenkins, 1895.

**Eotrigonia semiundulata granosa** (Pritchard, 1903).

See *Trigonia semiundulata* Jenkins var. *granosa* Pritchard, 1903.

**Eucrassatella camura** (Pritchard, 1903).

See *Crassatellites camurus* Pritchard, 1903.

**Eucrassatella kingicoloides** (Pritchard, 1903).

See *Crassatellites kingicoloides* Pritchard, 1903.

**Eucrassatella maudensis** (Pritchard, 1903).

See *Crassatellites maudensis* Pritchard, 1903.

**Glycimeris halli** Pritchard, 1903:—**Glycymeris halli** (Pritchard, 1903).

*Glycimeris halli* G. B. Pritchard, Proc Roy. Soc. Vic., n.s., 15 (2), p. 89, pl. 15, figs. 1, 2, 8, February, 1903.

*Glycymeris halli*, Pritchard: F. Chapman and F. A. Singleton, *ibid.*, 37 (1), p. 40, pl. 3, fig. 25; pl. 4, fig. 15, 1925.

M.U.G.D. No. 1783. Holotype, left valve, figured by Pritchard, loc. cit, figs. 1, 2, 1903.

M.U.G.D. No. 1784. PARATYPE, juvenile left valve, figured by Pritchard, loc. cit, fig. 8, 1903.

Lower Pliocene (Kalimnan).

Upper beds, Muddy Creek, near Hamilton, Victoria.

While the above type material is marked as from "M C."= Muddy Creek, this term is commonly used to include the upper beds at the adjacent stream, Grange Burn. Pritchard (loc. cit, p. 91, 1903) includes as localities "Grange Burn, between Forsyth's and Henty's, from the clays and sands of the upper series; Muddy Creek, from the upper beds below the State School." This latter locality is commonly known as MacDonald's, Muddy Creek. The paratype is probably, on its mode of preservation, from near Forsyth's, Grange Burn. whether the holotype is from Forsyth's or MacDonald's is uncertain.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Glycimeris halli** Pritchard var. **intermedius** Pritchard, 1903:—
**Glycymeris halli mistio** (Finlay, 1927).

*Glycimeris halli* Pritchard, variety *intermedius* G. B. Pritchard, Proc. Roy Soc. Vic., n.s., 15 (2), p. 90, pl 14,, figs 10, 11, February, 1903. Not *Pectunculus intermedius* Broderip, Proc Zool. Soc. Lond., pt. 2, p. 126, 1832.

*Glycymeris halli* var. *intermedia* Pritchard: F. Chapman and F. A. Singleton, Proc. Roy Soc. Vic., n.s., 37 (1), p. 41, 1925.

*Glycimeris halli mistio* H. J Finlay, nom. nov., Trans N.Z. Inst., 57, p 524, 1927.

M.U.G.D. No. 1785. SYNTYPE, right valve, figured by Pritchard, loc. cit, fig. 10, 1903.

M.U.G.D. No. 1786. SYNTYPE, right valve, figured by Pritchard, loc. cit., fig. 11, 1903.

Lower Pliocene (Kalimnan).

Upper beds, Muddy Creek, near Hamilton, Victoria.

The same remarks apply to this as to the preceding, but the coloration of the specimens suggests that they are from MacDonald's, Muddy Creek.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Glycimeris halli** Pritchard var. **paucicostatus** Pritchard, 1903:—
**Glycymeris halli paucicostata** (Pritchard, 1903).

*Glycimeris halli* Pritchard, variety *paucicostatus* G. B. Pritchard, Proc. Roy. Soc. Vic., n s., 15 (2), p. 90, pl. 14, fig. 12; pl. 15, fig. 9, February, 1903.

*Glycymeris halli* var. *paucicostata* Pritchard: F. Chapman and F. A. Singleton, *ibid.*, 37 (1), p. 42, 1925.

M.U.G.D. No. 1787. SYNTYPE, left valve, figured by Pritchard, loc. cit., pl. 14, fig. 12, 1903.

M.U.G D. No. 1788 SYNTYPE, left (?) valve, figured by Pritchard, loc. cit., pl. 15, fig. 9, 1903.

Lower Pliocene (Kalimnan).

"Sandy clays of Jimmy's Point, Gippsland" (Pritchard, loc. cit., p. 91, 1903) = Jemmy's Point, Kalimna, Gippsland Lakes, Victoria.

**Glycymeris (Grandaxinaea) granti** Singleton, 1932.

*Glycymeris (Grandaxinaea) granti* F. A. Singleton, Proc. Roy. Soc. Vic., n.s., 44 (2), p. 294, pl. 24, figs. 10*a*, 10*b*, 11, April, 1932.

M.U.G.D No. 1315. HOLOTYPE, left valve, figured by Singleton, loc. cit., figs. 10*a*, 10*b*, 1932.

M.U.G.D. No. 1316. PARATYPE, right valve, figured by Singleton, loc. cit., fig 11, 1932.

Miocene (Balcombian).

Lower Beds, Muddy Creek, near Hamilton, Victoria.

Pres. F. H. McK. Grant, 24 6 31.

## Glycymeris halli (Pritchard, 1903).

See *Glycimeris halli* Pritchard, 1903

## Glycymeris halli mistio (Finlay, 1927).

See *Glycimeris halli* Pritchard var. *intermedius* Pritchard, 1903.

## Glycymeris halli paucicostata (Pritchard, 1903).

See *Glycimeris halli* Pritchard var. *paucicostatus* Pritchard, 1903.

## Glycymeris (Veletuceta) pseudaustralis Singleton, 1941.

*Glycymeris (Veletuceta) pseudaustralis* F. A. Singleton, Proc. Roy Soc Vic., n s, 53 (2), p. 425, pl. 20, figs 4, 5, July, 1941.

M U G D. No. 1674. HOLOTYPE, right valve, figured by Singleton, loc. cit, fig. 4, 1941.

M.U G.D. No. 1675. PARATYPE, right valve, figured by Singleton, loc. cit., fig. 5, 1941.

Upper Pliocene (Werrikooian).

Glenelg River at "Roscoe's", Parish of Killara, Victoria. (Holotype No. 1674.)

Caldwell's Cliff, Glenelg River, Parish of Werrikoo, Victoria. (Paratype No. 1675.)

Coll and pres. F. A. Singleton, 12.12.40.

## Lahillia australica Singleton, 1943.

*Lahillia australica* F. A. Singleton, Proc, Roy. Soc. Vic., n.s., 55 (2), p. 273, pl. 12, figs. 3-5, October, 1943.

M.U.G.D. No. 1865. HOLOTYPE, left valve, figured by Singleton, loc. cit., fig. 5, 1943.

Eocene.

Second point north-west of Pebble Point, coastal cliffs 2½ miles south-east of Princetown, Victoria.

Coll. Jan., 1942, and pres. G. Baker, Jan., 1943.

M.U.G.D. No. 1866. PARATYPE, right valve, figured by Singleton, loc. cit., fig 3, 1943.

M.U.G.D. No. 1867. PARATYPE, left valve, figured by Singleton, loc. cit., fig. 4, 1943.

Eocene.

East side of Pebble Point, coastal cliffs 2½ miles south-east of Princetown, Victoria.

Coll. Oct., 1915, and pres. W. J. Parr, Dec., 1942.

**Leda acuticauda** Pritchard, 1901:—**Nuculana acuticauda** (Pritchard, 1901).

*Leda acuticauda* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 14 (1), p 27, pl. 3, figs 4, 4*a*, August, 1901.

M.U G.D. No. 1781. Holotype, paired valves, figured (right valve) by Pritchard, loc. cit., 1901.

M.U.G.D. No 1782. Paratype, right valve, unfigured.

Miocene (Balcombian).

Grice's Creek, between Frankston and Mornington, Port Phillip, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Leda fontinalis** Pritchard, 1901:—**Nuculana fontinalis** (Pritchard, 1901).

*Leda fontinalis* G B. Pritchard, Proc. Roy. Soc. Vic., n.s., 14 (1), p. 28, pl. 3, figs. 3, 3*a*, August, 1901.

M.U.G D. No. 1779. Holotype, paired valves, figured (left valve) by Pritchard, loc. cit., 1901. Now separated into left (1779A) and right (1779B) valves.

M.U.G.D. No. 1780. Paratype, left valve, unfigured.

"Lower beds of the Spring Creek or Bird Rock Bluff section, near Geelong" (Pritchard, loc. cit., p. 28, 1901) = Lower beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Limopsis chapmani** Singleton, 1932.

"*Limopsis aurita* (Brocchi)". F. McCoy, Prodromus Palaeont. Vic., decade 2, p. 23, pl. 19, figs. 5, 6, 6*a*, *b*, 7, 1875. R. Tate, Pap. Roy. Soc. Tas. for 1884, p. 212, 1885. R. Tate, Trans. Roy. Soc. S. Aust., 8, p. 134, 1886. R. M. Johnston, Geology of Tasmania, pl. 32, fig. 7, 1888. Not *Arca aurita* Brocchi, Conchiologia Fossile Subapennina, p. 485, pl. 11, figs. 9*a*, *b*, 1814.

"*Limopsis insolita* (G. B. Sowerby)": R. Tate, Trans. Roy. Soc. S. Aust., 8, p. 134, 1886. G. F. Harris, Cat. Tert Moll. Brit. Mus., pt. 1, p. 344, 1897. F. Chapman, Proc. Roy. Soc. Vic., n.s, 23 (2), p. 425, pl. 84, fig. 5; pl. 85, fig. 11, 1911. Not *Trigonocoelia insolita* G. B Sowerby, in C. Darwin, Geol. Obs. S. Amer., p. 252 (2nd ed., p. 608, 1876), pl. 2, figs. 20, 21, 1846.

*Limopsis chapmani* F. A Singleton, Proc Roy. Soc. Vic., n.s., 44 (2), p. 296, pl. 24, figs. 12-14; pl. 25, figs. 16*a-c*, 20th April, 1932.

M.U.G.D. No. 1317. Holotype, right valve of pair, figured by Singleton, loc. cit., figs. 16*a-c*, 1932.

M.U.G.D. No. 1318. Paratype, right valve, figured by Singleton, loc. cit., fig. 12, 1932

M.U.G.D. No. 1319. Paratype, right valve, figured by Singleton, loc. cit., fig. 13, 1932.

Miocene (Janjukian).

Lower beds, Bird Rock Cliffs, near Spring Creek, Torquay, Victoria.

Coll. and pres. F. A. Singleton, 29 2.32.

**Limopsis morningtonensis** Pritchard, 1901.

*Limopsis morningtonensis* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 14 (1), p. 24, pl. 2, figs 6, 6*a*, August, 1901. F. Chapman, *ibid.*, 23 (2), p. 420, pl. 83, fig. 1; pl. 85, fig. 7, 1911.

M.U.G.D. No. 1778. Holotype, left valve, figured by Pritchard, loc. cit., 1901.

Miocene (Balcombian).

"Eocene clays of Gellibrand River, coast section below Curdie's Steps" (Pritchard, loc. cit., p. 24, 1903), Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Limopsis** sp.

*Limopsis* sp nov. (?), F. A Singleton, Proc. Roy. Soc Vic., n.s., 55 (2), p 271, pl. 12, figs. 2*a*, *b*, October, 1943.

M.U.G.D. No. 1872. FIGURED SPECIMEN, left valve, figured by Singleton, loc. cit., 1943.

Eocene.

Second point north-west of Pebble Point, coastal cliffs 2½ miles south-east of Princetown, Victoria.

Coll. Jan., 1942, and pres. G. Baker, Jan, 1943.

**Lithophagus latecaudatus** Pritchard, 1903:—**Modiolus latecaudatus** (Pritchard, 1903).

*Lithophagus latecaudatus* G B. Pritchard, Proc Roy. Soc. Vic., n.s., 15 (2), p 88, pl. 14, fig. 4, February, 1903.

M U G.D. No. 1760. HOLOTYPE, left valve, figured by Pritchard, loc. cit, 1903.

Miocene (Janjukian).

"Lower beds of the Spring Creek series, or Bird Rock Bluff, near Geelong" (Pritchard, loc cit., p. 88, 1903) = Lower Beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria.

Dr. Pritchard states (personal communication) the type to have come from near the "ledge", a well-known locality near the base of the cliffs just south-west of Bird Rock The species is, however, not uncommon in the lowest bed, bluish clay, exposed in the centre of the half dome at this locality, and it is probable that the type is from this bed.

Purchased from Dr G. B. Pritchard, 11 10 39.

**Lucina gunyoungensis** Pritchard, 1903.

*Lucina gunyoungensis* G B. Pritchard, Proc. Roy. Soc. Vic, n.s., 15 (2), p 98, pl. 14, fig. 13, February, 1903.

M.U G.D. No. 1767. HOLOTYPE, right valve, figured by Pritchard, loc. cit., 1903.

Miocene (Balcombian).

Grey clays of Grice's Creek = Gunyoung Creek, Mornington.

Purchased from Dr. G. B. Pritchard, 11.10 39.

**Lucina (Prolucina) mitchelli** Pritchard, 1913:—**Prolucina mitchelli** (Pritchard, 1913).

*Lucina (Prolucina) mitchelli* G B. Pritchard, Proc. Roy. Soc. Vic., n s., 25 (2), p 363, pl. 29, figs. 1-3, March, 1913.

M.U.G.D. No. 1668. HOLOTYPE, figured by Pritchard, loc. cit, 1913.

Lower Devonian (Yeringian).

"Cave Hill Quarries, Lilydale. Silurian limestone fauna" (Pritchard, loc. cit., p. 364, 1913) = Mitchell's quarry, Cave Hill, near Lilydale, Victoria.

Collected by S. R. Mitchell. Purchased from Dr. G. B Pritchard, 11 10 39.

**Modiola praerupta** Pritchard, 1901:—**Modiolus praeruptus** (Pritchard, 1901).

*Modiola praerupta* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 14 (1), p. 25, pl. 2, figs. 3, 4, August, 1901.

M.U.G.D. No. 1774. HOLOTYPE, right valve, figured by Pritchard, loc. cit., 1901.

Miocene (Balcombian).

"Eocene Septarian Limestones, near the Old Cement Works, Balcombe's Bay, Mornington" (Pritchard, loc. cit, p. 26, 1901), Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Modiola pueblensis** Pritchard, 1901:—**Modiolus pueblensis** (Pritchard, 1901).

*Modiola pueblensis* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 14 (1), p. 26, pl. 3, fig. 1, August, 1901.

M.U.G.D. No 1777 HOLOTYPE, left valve, figured by Pritchard, loc. cit., 1901.

Miocene (Janjukian).

"Lower beds of the Spring Creek or Bird Rock Bluff, near Geelong" (Pritchard, loc. cit., p. 27, 1901) = Lower beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria.

Purchased from Dr. G B. Pritchard, 11.10 39.

**Modiolus praeruptus** Pritchard, 1901.

See *Modiola praerupta* (Pritchard, 1901).

**Modiolus pueblensis** (Pritchard, 1901).

See *Modiola pueblensis* Pritchard, 1901.

**Modiolaria balcombei** Pritchard, 1901:—**Musculus balcombei** (Pritchard, 1901).

*Modiolaria balcombei* G. B. Pritchard, Proc. Roy Soc. Vic., n s., 14 (1), p. 29, pl 3, fig. 2, August, 1901.

M.U.G.D. No. 1776. HOLOTYPE, figured by Pritchard, loc. cit., 1901.

Miocene (Balcombian).

"Eocene clays from the Old Cement Works, Balcombe's Bay, Mornington" (Pritchard, loc cit, p. 30, 1901), Victoria.

Purchased from Dr. G B Pritchard, 11.10.39.

**Modiolus latecaudatus** (Pritchard, 1903).

See *Lithophagus latecaudatus* Pritchard, 1903.

**Musculus balcombei** (Pritchard, 1901).

See *Modiolaria balcombei* Pritchard, 1901.

**Myochama trapezia** Pritchard, 1895.

*Myochama trapezia* G B. Pritchard, Proc. Roy. Soc. Vic, n.s., 7, p. 227, pl. 12, figs. 8, 9, January, 1895.

M.U G.D. No. 1747. SYNTYPE, left valve, figured by Pritchard, loc. cit., fig. 8, 1895.

M.U.G.D. No. 1748. SYNTYPE, right valve, figured by Pritchard, loc. cit., fig. 9, 1895.

Miocene (Balcombian).

Blue clays, Curlewis, Bellarine Peninsula, Victoria.

Purchased from Dr. G. B Pritchard, 11 10 39.

**Mytilicardia kalimnae** Pritchard, 1903.

*Mytilicardia kalimnae* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 15 (2), p. 97, pl. 12, fig 4, February, 1903.

M.U.G D. No. 1754. Holotype, left valve, figured by Pritchard, loc. cit., 1903.

Lower Pliocene (Kalimnan).

Jimmy's Point [ = Jemmy's Point], Kalimna, Gippsland Lakes, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Mytilus mooraboolensis** Pritchard, 1903:—**Aulacomya mooraboolensis** (Pritchard, 1903).

*Mytilus mooraboolensis* G B. Pritchard, Proc. Roy Soc Vic, n s., 15 (2), p. 88, pl. 14, fig. 1, February, 1903.

M.U.G.D. No. 1757. Holotype, right valve, figured by Pritchard, loc. cit., 1903.

Miocene (Janjukian).

"Lower beds of the Spring Creek series, or Bird Rock Bluff, near Geelong" (Pritchard, loc. cit., p 89, 1903) = Lower beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Nucula (Ennucula) gricei** Singleton, 1941.

"*Nucula tenisoni* Pritchard". F A Singleton, Proc Roy. Soc. Vic, n s, 44 (2), p. 290, pl. 24, figs. *5a*, *5b*, April, 1932. Not *Nucula tenisoni* G. B. Pritchard, *ibid.*, 8, p. 128, April, 1896.

*Nucula (Ennucula) gricei* F. A. Singleton, *ibid.*, 53 (2), p. 423, pl 20, figs. *1a*, *1b*, July, 1941.

M.U.G.D. No. 1311. Holotype, figured by Singleton, loc. cit., 1932 (as hypotype of *N. tenisoni*) and loc. cit., 1941.

Miocene (Balcombian).

Grice's Creek, between Frankston and Mornington, Victoria.

Coll and pres. F. A. Singleton, 29.2.32.

**Nucula kalimnae** Singleton, 1932:—**Nucula (Ennucula) kalimnae** Singleton, 1932.

"*Nucula tumida* Tenison-Woods": R. Tate, Trans. Roy. Soc. S. Aust., 8, p. 127, pl. 6, figs. *6a*, *6b*, May, 1886. Not *Nucula tumida* J. E. T. Woods, Pap. Proc. Roy. Soc. Tas. for 1876, p. 111, 1877.

*Nucula kalimnae* F. A. Singleton, Proc. Roy. Soc. Vic., n.s., 44 (2), p. 292, pl. 24, figs. *7a*, *7b*, *8a*, *8b*, 9, April, 1932.

M.U.G.D. No. 1312. Holotype, figured by Singleton, loc. cit., figs. *7a*, *7b*, 1932.

Lower Pliocene (Kalimnan).

Jemmy's Point, Kalimna, Victoria.

Coll. and pres. F. A. Singleton, 29.2.32.

M.U.G.D. No. 1313. Paratype, figured by Singleton, loc. cit., figs. *8a*, *8b*, 1932.

M.U.G.D. No. 1314. Paratype, figured by Singleton, loc. cit., fig. 9, 1932.

Lower Pliocene (Kalimnan).

Upper beds, Muddy Creek, near Hamilton, Victoria.

Purchased from T. Worcester.

**Nucula (Ennucula) kalimnae** Singleton, 1932.

See *Nucula kalimnae* Singleton, 1932.

**Nuculana acuticauda** (Pritchard, 1901).

See *Leda acuticauda* Pritchard, 1901.

**Nuculana fontinalis** (Pritchard, 1901).

See *Leda fontinalis* Pritchard, 1901.

**Nuculana paucigradata** Singleton, 1943.

*Nuculana paucigradata* F. A. Singleton, Proc. Roy. Soc. Vic., n.s., 55 (2), p. 268, pl. 12, figs. 1*a*, *b*, October, 1943.

M.U.G.D. No. 1868. HOLOTYPE, left valve, figured by Singleton, loc. cit., 1943.

Eocene.

Second point north-west of Pebble Point, coastal cliffs 2½ miles south-east of Princetown, Victoria.

Coll. Jan., 1942, and pres. G. Baker, Jan., 1943.

**Nuculana (Scaeoleda) killara** Singleton, 1941.

*Nuculana (Scaeoleda) killara* F. A. Singleton, Proc. Roy Soc Vic., n.s., 53 (2), p. 424, pl. 20, fig 2, July, 1941.

M.U.G.D. No. 1673. HOLOTYPE, left valve, figured by Singleton, loc. cit , 1941.

Upper Pliocene (Werrikooian).

Glenelg River at " Roscoe's ", Parish of Killara, Victoria.

Coll. 29.5.24, and pres. F. A. Singleton, 12.12.40.

Obs.—This specimen is missing It was formerly No. 21 in F. A. Singleton's private collection.

**Ostrea sinuata glenelgensis** Singleton, 1941.

*Ostrea sinuata glenelgensis* F A. Singleton, Proc. Roy. Soc. Vic., n.s., 53 (2), p 426, pl. 20, fig. 6, July, 1941.

M.U.G.D. No. 1676. SYNTYPE, figured by Singleton, loc. cit., 1941.

M.U G.D. No. 1677. SYNTYPE, counterpart of No. 1676.

Upper Pliocene (Werrikooian).

Glenelg River, Allotment 16A, Parish of Werrikoo, Western Victoria.

Coll. 30 5.24, and pres. F. A. Singleton, 12.12.40.

**Pecten asperrimus** Lamarck, 1819.

See *Chlamys asperrimus asperrimus* (Lamarck, 1819).

**Pinna cordata** Pritchard, 1895.

*Pinna cordata* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s , 7, p. 228, pl. 12, figs. 4, 5, January, 1895.

M.U.G.D. No. 1744. HOLOTYPE, paired valves, figured by Pritchard, loc. cit., 1895.

Miocene (Barwonian: probably Balcombian).

Sandy limestones, Barwon River, near its junction with the Native Hut Creek, Victoria.

Coll. J. Betheras. Purchased from Dr. G. B. Pritchard, 11.10 39.

**Prolucina mitchelli** (Pritchard, 1913).

See *Lucina (Prolucina) mitchelli* Pritchard, 1913.

**Trigonia semiundulata** Jenkins, 1865:—**Eotrigonia semiundulata** (Jenkins, 1865).

*Trigonia subundulata* M'Coy MS . H. M. Jenkins, Quart. Journ. Sci., 2, p. 363, 1865 (*nomen nudum*).

*Trigonia semiundulata* M'Coy MS.: H. M. Jenkins, *ibid.*, pl. opp. p. 630, fig. 6, 1865.

*Trigonia semiundulata* F. M'Coy, Geol. Mag., 3, p. 481, 1866.

*Trigonia semiundulata* F McCoy Prodromus Palaeont. Vic., decade 2, p. 22, pl. 19, figs. 4, 5, 1878.

*Trigonia semiundulata* McCoy: W. Bednall, Trans. Phil. Soc. Adelaide, for 1877-8, p. 81, 1878. R. Tate, Trans. Roy. Soc S. Aust., 8, p. 145, 1886. R. M. Johnston, Geol. Tas., p 235, pl. 29, fig. 5, 1888. R. Etheridge, jun, Rec. Geol. Surv. N.S. Wales, 3 (4), p 115, 1893.

*Trigonia subundulata* (M'Coy MS.) Jenkins: G. F. Harris, Cat. Tert. Moll. Brit. Mus., pt. 1, p. 352, 1897.

*Trigonia semiundulata* Jenkins· G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 15 (2), p. 91, pl 15, figs. 3, 4, 1903. J. Marwick, Rept. Aust. Assoc. Adv. Sci., 16, p. 327, 1924.

*Trigonia subundulata* Jenkins: H. Suter, N.Z. Geol. Surv. Pal. Bull. 2, p. 39, pl. 4, fig. 5, 1914.

M.U.G.D. No. 1768. Hypotype, right valve, figured by Pritchard, loc. cit., fig. 3, 1903

M.U.G.D No. 1769. Hypotype, right valve, figured by Pritchard, loc. cit., fig 4, 1903.

Miocene (Janjukian).

"Spring Creek series" (Pritchard, loc. cit., p. 103, 1903) = Lower Beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Trigonia semiundulata** Jenkins var. **granosa** Pritchard, 1903:—**Eotrigonia semiundulata granosa** (Pritchard, 1903).

*Trigonia semiundulata* Jenkins, variety *granosa*, G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 15 (2), p. 92, pl. 15, fig. 5, February, 1903.

M.U.G.D. No. 1770. Holotype, right valve, figured by Pritchard, loc. cit., 1903.

Miocene (Janjukian).

"Lower beds of the Spring Creek series, or Bird Rock Bluff, near Geelong" (Pritchard, loc. cit., p. 92, 1903) = Lower beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Trigonia semiundulata** Jenkins var. **lutosa** Pritchard, 1903:—**Eotrigonia lutosa** (Pritchard, 1903).

*Trigonia semiundulata* Jenkins, variety *lutosa* G B. Pritchard, Proc. Roy. Soc. Vic., n.s., 15 (2), p. 92, pl. 15, figs. 6, 7, February, 1903.

M.U.G.D. No. 1771. Syntype, left valve, figured by Pritchard, loc. cit., fig. 6, 1903.

M.U.G.D. No. 1772. Syntype, left valve, figured by Pritchard, loc. cit., fig. 7, 1903.

Miocene (Balcombian).

Lower Beds of Muddy Creek, Western Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Trigonia tatei** Pritchard, 1895:—**Eotrigonia intersitans** (Tate, 1896).

*Trigonia tatei* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 7, p. 225, pl. 12, figs. 1-3, January, 1895. G. F. Harris, Cat. Tert. Moll. Brit. Mus., pt. 1, p. 353, 1897. Not *Trigonia tatei* E. Holub and M. Neumayr, Denkschr. d. Math. Naturw. Cl. d. K. Akad. d. Wiss. Wien, 44, p. 275, pl. 2, fig. 3, 1881.

*Trigonia tatei* Pritchard: G. F. Harris, Cat. Tert. Moll. Brit. Mus., pt. 1, p. 353, 1897.

*Trigonia intersitans* R. Tate, nom. mut., in R. Tate and J. Dennant, Trans. Roy. Soc. S. Aust., 20 (1), p. 146 and footnote, September, 1896.

M.U.G.D. No. 1741. Syntype, left valve, figured by Pritchard, loc. cit., figs. 1, 3, 1895.

M.U.G.D. No. 1742. Syntype, right valve, figured by Pritchard. loc. cit., fig. 2, 1895.

M.U.G.D. No. 1743. Syntype, right valve, unfigured.

Miocene (Janjukian?).

"Lower Eocene calcareous sands, Moorabool Valley, near Maude" (Pritchard, loc. cit., p. 226, 1895) = Lower beds, Maude, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Venericardia excrescens** (Pritchard, 1903).

See *Cardita excrescens* Pritchard, 1903.

**Venericardia maudensis** (Pritchard, 1895).

See *Cardita maudensis* Pritchard, 1895.

**Verticordia excavata** Pritchard, 1901.

*Verticordia excavata* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 14 (1), p. 30, August, 1901.

M.U.G.D. No. 1799. Holotype, right valve, unfigured.

Miocene (Balcombian).

"Eocene clays from near the Old Cement Works, Balcombe's Bay, Mornington" (Pritchard, loc. cit., p. 30, 1901), Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

## SCAPHOPODA.

**Dentalium (Fissidentalium) gracilicostatum** Singleton, 1943.

*Dentalium (Fissidentalium) gracilicostatum* F. A. Singleton, Proc. Roy. Soc. Vic., n.s., 55 (2), p. 275, pl. 12, figs. 6*a*, *b*; pl. 13, figs. 9*a*, *b*, October, 1943.

M.U.G.D. No. 1871. Holotype, figured by Singleton, loc. cit., 1943.

Eocene.

Bay between first and second points north-west of Pebble Point, coastal cliffs 2½ miles south-east of Princetown, Victoria.

Coll. Jan., 1942, and pres. G. Baker, Jan., 1943.

## GASTEROPODA.

### **Apiotoma bassi** Pritchard, 1904.

*Apiotoma bassi* G. B. Pritchard, Proc Roy. Soc Vic., n s, 17 (1), p. 328, pl. 19, fig 11, September, 1904. H. J. Finlay, Trans. N.Z. Inst., 56 (1), p. 252, 1926. A W B. Powell, Bull. Auck. Inst. Mus., 2, p. 65, 1942. A. W. B. Powell, Rec. Auck. Inst. Mus., 3 (1), p. 20, 1944.

M.U.G.D. No. 1825. HOLOTYPE, figured by Pritchard, loc. cit., 1904.

Miocene (Janjukian).

"Clays of the Cape Otway section, near Point Flinders" (Pritchard, loc. cit., p. 329, 1904), Victoria.

Purchased from Dr. G. B. Pritchard, 11.10 39.

### **Apiotoma granti** (Pritchard, 1904).

See *Pleurotoma granti* Pritchard, 1904.

### **Astele millegranosa** Pritchard, 1904.

*Astele millegranosa* G. B. Pritchard, Proc. Roy. Soc. Vic., n s., 17 (1), p. 332, pl 19, figs. 7, 8, September, 1904.

M.U.G D. No. 1828. HOLOTYPE, figured by Pritchard, loc. cit., 1904.

Miocene (Balcombian).

Lower beds, Muddy Creek, near Hamilton, Victoria.

Purchased from Dr. G. B. Pritchard, 11 10.39.

### **Astralium (Imperator) johnstoni** Pritchard, 1896:—**Imperator johnstoni** (Pritchard, 1896).

*Astralium (Imperator) johnstoni* G. B. Pritchard, Proc. Roy. Soc. Vic, n.s, 8, p. 116, April, 1896

M.U.G.D. No. 1810. SYNTYPE, internal cast in two pieces (1810A and 1810B) which fit together, unfigured.

Miocene (Balcombian?)

"Royal Park" (Pritchard, loc. cit., p. 118, 1896) = Lower beds, Royal Park railway cutting, between Flemington and Royal Park stations, near Melbourne, Victoria.

Collected by Rev. M. Ramage (?). Purchased from Dr. G B. Pritchard, 11.10.39.

M.U.G.D. No. 1811. SYNTYPE, external mould, unfigured.

M.U.G.D. No. 1812. SYNTYPE, internal cast (not a counterpart of preceding), unfigured.

Miocene (Balcombian?).

"Eocene ferruginous beds of Keilor" (Pritchard, loc. cit., p. 118, 1896) = Green Gully, near Keilor, Victoria.

Collected by T. S. Hart (?). Purchased from Dr. G. B. Pritchard, 11.10.39.

Obs.—In the synonymy cited by Pritchard is included *Imperator hudsoniana* R.M. Johnston, Geology of Tasmania, pl. 29, figs. 12, 12*a*, 1888, which would seem to be the valid name for the present species. Since Pritchard (loc. cit.) regards their identity as extremely doubtful and the two come from different geological horizons, Pritchard's name has been allowed to stand.

**Aulica weldii** (T. Woods, 1876).

See *Voluta weldii* T. Woods, 1876.

**Aulica weldii angustior** (Pritchard, 1913).

See *Voluta weldii* var. *angustior* Pritchard, 1913.

**Aulica weldii intermedia** (Pritchard, 1913).

See *Voluta weldii* var. *intermedia* Pritchard, 1913.

**Austrolithes bulbodes** (Tate, 1888).

See *Clavella bulbodes* (Tate, 1888).

**Austrolithes platystropha** (Pritchard, 1904).

See *Clavella platystropha* Pritchard, 1904.

**Bankivia howitti** Pritchard, 1903.

*Bankivia howitti* G. B Pritchard, Proc Roy. Soc Vic, n s., 17 (1), p. 334, pl. 18, fig 1, September, 1904.

M.U.G.D. No. 1817. HOLOTYPE, figured by Pritchard, loc. cit., 1904.

Lower Pliocene (Kalimnan).

("Sandy clays of Jimmy's Point, Gippsland" (Pritchard, loc. cit., p. 334, 1904) = Jemmy's Point, Kalimna, Gippsland Lakes, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Cantharidus serratulus** Pritchard, 1904.

*Cantharidus serratulus* G. B Pritchard, Proc. Roy. Soc Vic., n.s., 17 (1), p. 331, pl. 19, figs. 5, 6, September, 1904.

M U G.D. No. 1826. SYNTYPE, figured by Pritchard, loc. cit., fig. 5, 1904.

M.U.G.D. No. 1827 SYNTYPE, figured by Pritchard, loc. cit., fig. 6, 1904.

Miocene (Balcombian).

Lower beds, Muddy Creek, near Hamilton, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Clavella bulbodes** (Tate, 1888) :—**Austrolithes bulbodes** (Tate, 1888).

*Fusus bulbodes* R. Tate, Trans Roy. Soc. S. Aust., 10, p. 139, pl. 7, fig. 8, 1888.

*Clavilithes bulbodes* R. Tate, Journ. Roy. Soc. N.S. Wales, 27, p. 170, 1894.

*Clavella bulbodes* Tate: G. B Pritchard, Proc. Roy. Soc. Vic., n.s., 14 (1), p. 48, 1901. G. B. Pritchard, *ibid.*, 17 (1), p. 320, pl. 18, figs. 2, 3, 1904.

M.U.G.D. No. 1800. HYPOTYPE, figured by Pritchard, loc. cit., fig. 3, 1904.

M.U.G.D. No. 1801. HYPOTYPE, juvenile, figured by Pritchard, loc. cit., fig. 2, 1904.

Miocene (Balcombian).

"Clays of the Old Cement Works, Balcombe's Bay" (Pritchard, loc. cit., p. 322, 1904), Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Clavella platystropha** Pritchard, 1904: — **Austrolithes platystropha** (Pritchard, 1904).

*Clavella platystropha* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 17 (1), p. 322, pl. 18, figs. 4, 5, September, 1904.

M.U.G.D. No. 1802. Holotype, figured by Pritchard, loc. cit., fig. 4, 1903.

M.U.G.D. No. 1803. Paratype, juvenile, figured by Pritchard, loc. cit., fig. 5, 1903.

Miocene (Balcombian).

"Lower Beds of Muddy Creek sections near Hamilton, Western Victoria" (Pritchard, loc. cit., p. 323, 1904).

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Collonia geelongensis** Pritchard, 1904.

*Collonia geelongensis* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 17 (1), p. 330, pl. 18, figs. 8, 9, September, 1904.

M.U.G.D. No. 1819. Holotype, figured by Pritchard, loc. cit., 1904.

Miocene (Balcombian)

"Clays over Polyzoal Rock, Filter Quarries, Batesford, near Geelong" (Pritchard, loc. cit., p. 330, 1904), Victoria

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Collonia otwayensis** Pritchard, 1904.

*Collonia otwayensis* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 17 (1), p. 331, pl. 18, figs. 6, 7, September, 1904.

M.U.G.D. No. 1818. Holotype, figured by Pritchard, loc. cit., 1904.

Miocene (Janjukian).

"Clays and sandy clays of the Cape Otway section near Point Flinders" (Pritchard, loc. cit., p. 331, 1904), Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Columbella approximans** Pritchard, 1904.

*Columbella approximans* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 17 (1), p. 325, pl. 18, figs. 12, 13, September, 1904.

M.U.G.D. No. 1821. Holotype, figured by Pritchard, loc. cit., 1904.

Miocene (Balcombian).

"Clays of the Old Cement Works, Balcombe's Bay, Mornington" (Pritchard, loc. cit., p. 325, 1904), Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Columbella balcombensis** Pritchard, 1904.

*Columbella clathrata* R. Tate MS.

*Columbella balcombensis* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 17 (1), p. 324, pl 18, figs. 10, 11, September, 1904.

M.U.G.D. No. 1820. Holotype, figured by Pritchard, loc. cit., 1904.

Miocene (Balcombian).

"Clays of the Old Cement Works, Balcombe's Bay" (Pritchard, loc. cit., p. 324, 1904), Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Epideira selwyni** (Pritchard, 1904).

See *Pleurotoma selwyni* Pritchard, 1904.

**Epideira selwyni suppressa** Finlay, 1927.

See *Pleurotoma selwyni* var. *laevis* Pritchard, 1904.

**Ericusa fulgetroides** (Pritchard, 1898).

See *Voluta fulgetroides* Pritchard, 1898.

**Eutrochus fontinalis** Pritchard, 1904.

*Eutrochus fontinalis* G. B. Pritchard, Proc Roy. Soc. Vic., n s , 17 (1), p. 333, pl 19, fig. 9, September, 1904

M.U.G.D. No. 1816. HOLOTYPE (imperfect), figured by Pritchard, loc. cit , 1904.

Miocene (Janjukian).

"Lower beds of the Spring Creek series, or Bird Rock Bluff, near Geelong" (Pritchard, loc cit., p. 334, 1904) = Lower beds, Bird Rock cliffs, near Torquay, Victoria

Purchased from Dr. G. B Pritchard, 11.10.39

**Imperator johnstoni** (Pritchard, 1896).

See *Astralium (Imperator) johnstoni* Pritchard, 1896.

**Latirofusus cingulata** Pritchard, 1896.

*Latirofusus cingulata* G B. Pritchard, Proc. Roy. Soc. Vic., n.s., 8, p. 83, pl. 2, figs. 5, 6, April, 1896.

M.U.G.D. No. 1814. HOLOTYPE, figured by Pritchard, loc. cit., 1896.

Miocene (Janjukian).

"Lower beds of the lower eocene series of Spring Creek, near Geelong, Victoria" (Pritchard, loc. cit., p 84, 1896) = Lower beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria.

Purchased from Dr. G. B. Pritchard, 11 10.39.

**Lophiotoma murrayana** (Pritchard, 1904).

See *Pleurotoma murrayana* Pritchard, 1904.

**Murex wallacei** Pritchard, 1898.

*Murex wallacei* G B. Pritchard, Proc Roy. Soc. Vic., n.s., 11 (1), p. 104, pl. 7, fig. 3, September, 1898.

M U.G.D. No. 1831. HOLOTYPE, figured by Pritchard, loc. cit., 1898.

Miocene (Balcombian).

"Eocene clays of Mornington" (Pritchard, loc. cit., p. 105, 1898).

Coll. W. Wallace. Purchased from Dr. G. B. Pritchard, 11.10.39.

**Niso kimberi** Pritchard, 1906.

*Niso kimberi* G. B. Pritchard, Vic. Naturalist, 23 (6), p. 119, 4th October, 1906.

M U.G.D. No. 1873. HOLOTYPE, unfigured.

Miocene (Janjukian).

"Lower beds of the Aldinga series, South Australia" (Pritchard, loc. cit., p. 119, 1903) = Lower beds, Aldinga Bay, South Australia.

Coll. W. J. Kimber. Purchased from Dr. G. B. Pritchard, 11.10.39.

**Notopeplum liratum** (Johnston, 1880).

See *Voluta lirata* Johnston, 1880.

**Pleurotoma granti** Pritchard, 1904:—**Apiotoma granti** (Pritchard, 1904).

*Pleurotoma granti* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 17 (1), p. 336, pl. 19, fig. 3, September, 1904.

*Apiotoma granti* Pritchard: A. W. B Powell, Bull. Auck. Inst. Mus., 2, p. 65, 1942 [as *Pleurotoma granti* Pritchard]. A. W. B. Powell, Rec. Auck. Inst Mus., 3 (1), p. 21, 1944.

M.U.G.D. No. 1807. Holotype, figured by Pritchard, loc. cit, 1904.

Miocene (Balcombian).

Lower beds, Muddy Creek, near Hamilton, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10 39.

**Pleurotoma murrayana** Pritchard, 1904:—**Lophiotoma murrayana** (Pritchard, 1904).

*Pleurotoma murrayana* G. B Pritchard, Proc. Roy. Soc. Vic., n.s., 17 (1), p. 335, pl. 19, fig. 10, September, 1904.

*Lophiotoma murrayana* (Pritchard, 1904): A. W. B. Powell, Rec. Auck. Inst. Mus, 3 (1), p. 9, 1944.

M.U.G.D. No. 1824. Holotype, figured by Pritchard, loc. cit., 1904.

Miocene (Barwonian; probably Balcombian).

"River Murray Cliffs, near Morgan" (Pritchard, loc. cit., p. 336, 1904), South Australia. The label on the original box states "River Murray Cliffs near Mannum", which is evidently a *lapsus*.

Purchased from Dr. G. B. Pritchard, 11 10.39.

**Pleurotoma selwyni** Pritchard, 1904:—**Epideira selwyni** (Pritchard, 1904).

*Pleurotoma selwyni* G B. Pritchard, Proc. Roy. Soc. Vic., n.s., 17 (1), p. 326, pl. 19, fig. 1, September, 1904.

*Turris selwyni* (Pritchard, 1904): A. W. B Powell, Rec. Auck. Inst. Mus, 3 (1), p. 8, 1944.

M.U.G.D. No. 1822. Holotype, figured by Pritchard, loc. cit., 1904.

Miocene (Balcombian).

Lower beds of Muddy Creek, near Hamilton, Western Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Pleurotoma selwyni** var. **laevis** Pritchard, 1904:—**Epideira selwyni suppressa** Finlay, 1927.

*Pleurotoma selwyni* variety *laevis* G. B. Pritchard, Proc Roy. Soc. Vic., n.s., 17 (1), p. 328, pl 19, fig. 2, September, 1904. Not *Pleurotoma laevis* Bellardi, M. R. Acc. Sci. Torino, [2] 9, p. 542, 1848 Nor *Pleurotoma laevis* F. W. Hutton, Cat Marine Moll. N.Z, p 12, 1873 (=*Splendrillia aoteana* H. J. Finlay, nom. nov., Trans. N.Z Inst., 61 (1), p. 47, 1930).

*Epideira selwyni suppressa* H. J. Finlay, nom. nov., Trans. N.Z. Inst., 57, p. 516, 19th January, 1927.

*Epidirona suppressa* (Finlay, 1927): A W. B. Powell, Rec. Auck. Inst. Mus., 3 (1), p. 16, 1944.

M.U.G.D. No. 1823. Holotype, figured by Pritchard, loc. cit., 1904.

Miocene (Balcombian).

Lower beds of Muddy Creek, near Hamilton, Western Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

Obs.—Finlay, loc. cit, 1927, cites as another homonym *Pleurotoma laevis* Bell, 1890, for which he provides *Raphitoma belliana*, nom. nov. But at the reference cited (Rept. Brit. Assoc. Adv. Sci. 60th Meeting (Leeds, 1890), p. 410, 1891) A. Bell includes in a list *Pleurotoma laevis* (n. sp.), which is a *nomen nudum*, next appearing in the synonymy of *Raphitoma laevis* (A. Bell) F. W. Harmer, Plioc. Moll. Gt. Britain, 2 (1), Palaeontogr. Soc., Lond., 72, for 1918, p. 523, pl. 47, fig. 10, December, 1920. This latter combination, which must be cited as *Raphitoma laevis* Harmer, 1922, does not clash with *Pleurotoma laevis* and therefore *Raphitoma belliana* Finlay, 1927, falls in its synonymy.

## **Pleurotomaria bassi** Pritchard, 1903.

*Pleurotomaria bassi* Pritchard, Proc. Roy. Soc. Vic., n.s, 16 (1), p 85, pl 13, figs. 1, 2, September, 1903.

M.U.G.D. No. 1797. HOLOTYPE, figured by Pritchard, loc. cit., 1903.

Miocene (Janjukian).

" Basal horizon of the Table Cape Beds, Tasmania, in coarse ferruginous grits " Pritchard, loc. cit., p. 86, 1903).

Purchased from Dr. G. B Pritchard, 11 10 39.

## **Pleurotomaria tertiaria** McCoy, 1876.

*Pleurotomaria Tertiaria* F. McCoy, Prodromus Palaeont. Vic., decade 3, p. 23, pl 25, figs. 1, 1*a*, 1*b*, 1876.

*Pleurotomaria tertiaria* McCoy· G. B. Pritchard, Proc. Roy. Soc. Vic., n s., 16 (1), p 83, pl. 14, figs. 1-4, 1903.

M U.G.D. No. 1798. HYPOTYPE, figured by Pritchard, loc. cit., figs. 1-3, 1903.

Miocene (Barwonian, probably Balcombian).

" ? Corio Bay or Lower Moorabool Valley" (Pritchard, loc. cit., p. 91, 1903) Victoria. The specimen (No. 1798) when received from Dr. Pritchard was in a box marked "OAH. Geelong", which refers to Orphanage Hill, Fyansford, near Geelong, Victoria, a locality in the Lower Moorabool Valley.

Coll. Rev. A. W. Cresswell. Purchased from Dr. G. B. Pritchard, 11.10.39.

## **Pterospira gatliffi** (Pritchard, 1898).

See *Voluta gatliffi* Pritchard, 1898.

## **Pterospira stephensi** (Johnston, 1880).

See *Voluta stephensi* Johnston, 1880.

## **Solutofusus carinatus** Pritchard, 1898.

*Solutofusus carinatus* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 11 (1), p. 102, pl. 7, figs. 1, 1*a*, 2, September, 1898.

M.U.G.D. No. 1829. HOLOTYPE, figured by Pritchard, loc. cit., figs. 1, 1*a*, 1898.

M.U.G.D. No. 1830. PARATYPE, figured by Pritchard, loc. cit., fig. 2, 1898.

Miocene (Balcombian).

"Eocene clays of Balcombe's Bay, Mornington" (Pritchard, loc. cit., p. 103, 1898), Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Tentaculites matlockiensis** Chapman, 1904.

*Tentaculites matlockiensis* F. Chapman, Proc. Roy. Soc Vic., n.s., 16 (2), p. 338, pl. 31, figs. 1-3, 5, March, 1904. E. D. Gill, *ibid*, 53 (1), p. 150, pl. 4, figs. 4, 5, 1941.

M.U.G.D. No. 1734. HYPOTYPE, internal cast, figured by Gill, loc. cit., fig. 4, 1941.

M.U.G.D. No. 1735. COUNTERPART OF HYPOTYPE, external mould (counterpart of No. 1734), unfigured

"Silurian (Jordanian)" (Gill, loc. cit., p. 161, 1941) = Upper Silurian (Tanjilian).

Cutting on west bank of Muddy Creek (near McMahon's Creek) on south side of Warburton-Wood's Point Road, Victoria.

Presented by Rev. E. D. Gill, 24.5.41.

**Tremanotus pritchardi** Cresswell, 1893: — **Trematonotus pritchardi** (Cresswell, 1893).

*Tremanotus* [*sic*] *pritchardi* A. W. Cresswell, Proc. Roy. Soc. Vic., n s., 5, p. 42 and addenda slip opposite p. 38, pl. 8, fig. 1 (3 figs.), May, 1893.

M.U.G D. No. 1666. HOLOTYPE, figured by Cresswell, loc. cit., 1893.

M.U.G.D. No. 1667. COUNTERPART OF HOLOTYPE, part of external mould, unfigured.

Lower Devonian (Yeringian).

Cave Hill Quarry, Lilydale, Victoria. The type material is stated by Dr. Pritchard (personal communication, 1939) to be from the south face of the quarry (Mitchell's quarry).

Purchased from Dr. G. B. Pritchard, 11 10 39.

**Trematonotus pritchardi** (Cresswell, 1893).

See *Tremanotus pritchardi* Cresswell, 1893.

**Trophon selwyni** Pritchard, 1896.

*Trophon selwyni* G B. Pritchard, Proc. Roy. Soc. Vic., n.s., 8, p. 79, pl. 2, fig. 7, April, 1896.

M.U.G.D. No. 1815. HOLOTYPE, figured by Pritchard, loc. cit., 1896.

Miocene (Janjukian).

"Lower beds of the lower eocene of Spring Creek, near Geelong, Victoria" (Pritchard, loc. cit., p. 81, 1896) = Lower beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Turbo hamiltonensis** Pritchard, 1904:—**Turbo (Subninella) grangensis** Pritchard, 1906.

*Turbo paucigranosa* R Tate MS.: J. Dennant, Trans. Roy. Soc. S. Aust, 11, p. 48, 1889 (list name).

*Turbo hamiltonensis* G. B. Pritchard, Proc. Roy. Soc Vic, n.s., 17 (1), p. 329, pl. 19, fig. 4, September, 1904. Not *Turbo hamiltonensis* G. F. Harris, Cat. Tert. Moll. Brit. Mus., pt. 1, p. 274, pl. 8, fig. 3*a-c*, 1897.

*Turbo grangensis* G. B. Pritchard, nom. mut., Vic. Naturalist, 23 (6), p. 117, 4th October, 1906. F. Chapman, Proc. Roy. Soc. Vic., n.s, 35 (1), p. 10, pl. 2, figs. 13, 14, 1922.

M.U.G.D. No. 1808. HOLOTYPE, figured by Pritchard, loc. cit., 1904.

Lower Pliocene (Kalimnan).

"Upper beds of the Grange Burn, near Hamilton, Western Victoria" (Pritchard, loc. cit., p. 330, 1904).

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Turbo (Subninella) grangensis** Pritchard, 1906.

See *Turbo hamiltonensis* Pritchard, 1904.

**Voluta fulgetroides** Pritchard, 1898:—**Ericusa fulgetroides** (Pritchard, 1898).

*Voluta fulgetroides* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 11 (1), p. 105, pl. 7, fig. 4, September, 1898.

M.U.G.D. No. 1804. HOLOTYPE, figured by Pritchard, loc. cit., 1898.

Lower Pliocene (Kalimnan).

"Miocene beds of Muddy Creek" (Pritchard, loc. cit, p. 106, 1898) = Upper beds, Muddy Creek, near Hamilton, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Voluta gatliffi** Pritchard, 1898:—**Pterospira gatliffi** (Pritchard, 1898).

*Voluta gatliffi* G. B. Pritchard, Proc. Roy. Soc. Vic, n s., 11 (1), p. 108, pl. 8, fig. 6, September, 1898.

M.U.G.D. No. 1805. HOLOTYPE, figured by Pritchard, loc. cit., 1898.

Miocene (Balcombian).

"Eocene beds of Muddy Creek, Western Victoria" (Pritchard, loc. cit., p. 109, 1898) = Lower beds, Muddy Creek, near Hamilton, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10 39.

**Voluta halli** Pritchard, 1896.

*Voluta halli* G. B. Pritchard, Proc. Roy Soc Vic, n s., 8, p 101, pl. 2, figs. 1-3, April, 1896 G B. Pritchard, *ibid*, 26 (1), p. 198, 1913.

M U.G.D. No. 1789. HOLOTYPE, figured by Pritchard, loc. cit., fig. 1, 1896.

Miocene (Janjukian).

"Lower Eocene beds at Spring Creek, near Geelong" (Pritchard, loc. cit., p. 102, 1896) = Lower beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria.

Purchased from Dr. G. B Pritchard, 11 10 39.

M.U.G.D. No. 1790. PARATYPE, juvenile, figured by Pritchard, loc. cit., fig. 2, 1898.

M.U.G.D. No. 1791. PARATYPE, juvenile, figured by Pritchard, loc. cit., fig. 3, 1898.

Miocene (Balcombian).

"Eocene clays of Curlewis, Bellarine Peninsula, Victoria" (Pritchard, loc. cit., p. 102, 1896).

Purchased from Dr. G. B Pritchard, 11 10.39.

**Voluta hamiltonensis** Pritchard, 1898.

*Voluta hamiltonensis* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 11 (1), p. 107, pl. 8, fig. 5, September, 1898.

M.U.G.D. No. 1832. HOLOTYPE, figured by Pritchard, loc. cit., 1898.

Miocene (Balcombian).

"Eocene beds of Muddy Creek, Western Victoria" (Pritchard, loc. cit., p. 108, 1898) = Lower beds, Muddy Creek, near Hamilton, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Voluta lirata** Johnston, 1880:—**Notopeplum liratum** (Johnston, 1880).

"*Voluta lirata* R. M. Johnston," Pap. Roy. Soc. Tas. for 1879, p. 37, 1880. Not *Voluta lirata* Johnston: R. Tate, Trans. Roy. Soc. S. Aust., 11, p. 130, pl. 2, fig. 4, 1889; nor G. F. Harris, Cat. Tert. Moll. Brit. Mus., pt. 1, p. 103, pl. 4, fig. 12, 1897 (=*V. costellifera* Tate, var.).

*Voluta allporti* R. M. Johnston, Geol. Tas., pl. 30, fig. 10, 1888. Not *Voluta allporti* R. M. Johnston, Pap. Roy. Soc. Tas. for 1879, p. 35, 1880.

*Voluta lirata* Johnston: G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 26 (1), p. 197, pl. 20, figs. 7, 8, 1913.

M.U.G.D. No. 1795. HYPOTYPE, figured by Pritchard, loc. cit., 1913.

Miocene (Janjukian).

"Table Cape Beds, Tasmania" (Pritchard, loc. cit., p. 192, 1913) = Table Cape, near Wynyard, Tasmania. The "Table Cape" beds are actually at the Fossil Bluff, west of the mouth of the Inglis River at Wynyard. The colour and matrix suggest the lower or "Crassatella" bed at this locality.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Voluta pueblensis** Pritchard, 1898.

*Voluta pueblensis* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 11 (1), p. 109, pl. 8, fig. 7, September, 1898.

M.U.G.D. No. 1806. HOLOTYPE, figured by Pritchard, loc. cit., 1898.

Miocene (Janjukian).

"Lower horizon of the Eocene beds of Spring Creek, south of Geelong" (Pritchard, loc. cit., p. 110, 1898. Erroneously given as "Muddy Creek" on explanation to plate, p. 111, 1898) = Lower beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Voluta spenceri** Pritchard, 1896.

*Voluta spenceri* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 8, p. 98, pl. 4, figs. 1, 2, April, 1896. G. B. Pritchard, *ibid.*, 26 (1), p. 198, 1913.

M.U.G.D. No. 1813. PARATYPE, imperfect apical portion, figured by Pritchard, loc. cit., fig. 2, 1896.

Miocene (Balcombian).

"Eocene clays of Curlewis, Bellarine Peninsula, Victoria."

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Voluta stephensi** Johnston, 1880:—**Pterospira stephensi** (Johnston, 1880).

*Voluta stephensi* R. M. Johnston, Pap. Roy. Soc. Tas. for 1879, p. 35, 1880. G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 8, p. 94, 1896. G. B. Pritchard, *ibid.*, 26 (1), p. 195, pl. 21, figs. 3, 4, September, 1913.

M.U.G.D. No. 1796. HYPOTYPE, figured by Pritchard, *loc. cit.*, 1913.

Miocene (Janjukian).

"Table Cape Beds, Tasmania" (Pritchard, loc. cit., p. 192, 1913) = Table Cape, near Wynyard, Tasmania. Colour and matrix definitely allocate it to the lower or "Crassatella" bed at this, the type locality.

**Voluta weldii** T. Woods, 1876:—**Aulica weldii** (T. Woods, 1876).

*Voluta Weldii* J. E. T. Woods, Pap. Roy. Soc. Tas. for 1875, p. 24, pl. 1, fig. 2, 1876. R. M. Johnston, Geol. Tas., pl. 30, figs. 6-6*b* (*non* fig. 7), 1888. R. Tate, Trans. Roy. Soc. S. Aust., 11, p. 134, 1889. G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 8, p. 93, 1896.

*Voluta (Aulica) weldi* T. Woods. G. F. Harris, Cat. Tert. Moll. Brit. Mus., pt. 1, p. 102, 1897.

*Voluta (Aulica) Weldii* T. Woods. R. Tate, Journ. Roy. Soc. N.S. Wales, 31, p. 386, 1898.

*Voluta weldii* T. Woods. G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 26 (1), p. 193, pl. 20, fig. 1, 1913.

M.U.G.D. No. 1792. Hypotype, figured by Pritchard, loc. cit., 1913.

Miocene (Janjukian)

"Table Cape Beds, Tasmania" (Pritchard, loc. cit., p. 192, 1913) = Table Cape, near Wynyard, Tasmania. The matrix suggests the upper or Turritella bed at this, the type locality.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Voluta weldii** var. **angustior** Pritchard, 1913:—**Aulica weldii angustior** (Pritchard, 1913).

*Voluta weldii* variety *angustior* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 26 (1), p. 194, pl. 20, figs. 4, 5, September, 1913.

M.U.G.D. No. 1794. Holotype, figured by Pritchard, loc. cit., 1913.

"Table Cape Beds, Tasmania" (Pritchard, loc. cit., p. 192, 1913) = Table Cape, near Wynyard, Tasmania. Colour and matrix suggest the lower or "Crassatella" bed at this locality.

**Voluta weldii** var. **intermedia** Pritchard, 1913:—**Aulica weldii intermedia** (Pritchard, 1913)

*Voluta weldii* variety *intermedia* G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 26 (1), p. 193, pl. 20, figs. 2, 3, September, 1913.

M.U.G.D. No. 1793. Holotype, figured by Pritchard, loc. cit., 1913.

Miocene (Balcombian).

Lower beds, Muddy Creek, near Hamilton, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

## CEPHALOPODA.

**Aturoidea distans** Teichert, 1943.

*Aturoidea distans* C. Teichert, Proc. Roy. Soc. Vic., n.s., 55 (2), p. 260, text fig. 1, pl. 11, figs. 1-4, October, 1943.

M.U.G.D. No. 1860. Holotype, figured by Teichert, loc. cit., text fig. 1, pl. 11, fig. 1, 1943.

M.U.G.D. No. 1861. Paratype, figured by Teichert, loc. cit., pl. 11, figs. 2, 3, 1943.

M.U.G.D. No. 1862. Paratype, figured by Teichert, loc. cit., pl. 11, fig. 4, 1943.

Eocene.

Grit band 30-40 feet above Jurassic-Tertiary unconformity, second point north-west of Pebble Point, south-east of Princetown, Victoria.

Coll. Jan., 1942, and pres. G. Baker, Jan., 1943.

**Nautilus geelongensis** Foord, 1891.

*Nautilus geelongensis* A. H. Foord, Cat. Foss. Cephal Brit. Mus, pt. 2, p. 332, figs. 69 *a-c* (woodcut), 1891 F. Chapman, Proc Roy Soc. Vic, n.s., 27 (2), p. 354, pl. 4, figs. 7-9, 1915 C. Teichert, *ibid.*, 55 (2), p 263, text fig. 4 (p. 262), 1943.

M.U.G.D. No. 1863. Hypotype, suture figured by Teichert, loc. cit., 1943.

Upper Miocene (Cheltenhamian).

"Cheltenham" = Upper beds, Beaumaris, Victoria. The specimen is an internal cast in brown sandstone.

Purchased from T. Worcester.

**Nautilus victorianus** Teichert, 1943.

*Nautilus victorianus* C. Teichert, Proc. Roy. Soc Vic., n.s., 55 (2), p. 262, text fig 2, pl. 11, figs. 5-7, October, 1943

M.U.G.D. No. 1864. Holotype, figured by Teichert, loc. cit., 1943.

Eocene.

Grit band 30-40 feet above Jurassic-Tertiary unconformity, second point north-west of Pebble Point, south-east of Princetown, Victoria.

Coll. Jan., 1942, and pres. G. Baker, Jan., 1943.

**Tetrabelus macgregori** Glaessner, 1945.

*Tetrabelus magregori* M. F. Glaessner, Proc. Roy. Soc. Vic., n.s., 56 (2), p. 160, pl. 6, figs. 12*a*, *b*, 1945

M.U.G.D. No. 1876. Holotype, figured by Glaessner, *loc cit.*, 1945.

Cretaceous (Purari Formation: Aptian-Albian).

Paw Creek, Purari River, Papua.

Coll. S. W. Carey and pres. M. F. Glaessner, 29.9.44.

## CIRRIPEDIA.

**Lepas pritchardi** T. S. Hall, 1902.

*Lepas pritchardi* T. S. Hall, Proc. Roy. Soc. Vic., n.s., 15 (1), p. 83, pl. 11. figs. 11-13, August, 1902.

M.U.G.D. No. 1809. Paratype (?), unfigured.

Miocene (Janjukian).

"Spring Creek" (Hall, loc. cit., p. 84, 1902) = Bird Rock Cliffs, near Spring Creek, Torquay, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

Obs.—This specimen is mentioned by Hall in his original description but it is not specifically stated to be a supplementary type. The "type" (i.e., holotype) is from Waurn Ponds and is now in the National Museum, Melbourne.

## PHYLLOCARIDA.

### **Hymenocaris ornata** Sherrard, 1930.

*Hymenocaris ornata* K. Sherrard, Proc. Roy. Soc. Vic., n.s., 42 (2), p. 136, pl. 11, figs 1-3, 13th March, 1930.

M.U.G.D. No. 993 HOLOTYPE, figured by Sherrard, loc. cit., 1930.

M.U.G.D. No. 994. COUNTERPART OF HOLOTYPE No. 993.

Lower Ordovician (Lancefieldian, Zone La 2).

Quarry, Allot 56, Parish of Goldie, near Lancefield, Victoria.

Coll. Sept., 1923 and pres. Mrs. K. Sherrard, 12.12.29.

## MEROSTOMATA.

### **Hemiaspis tunnecliffei** Chapman, 1932.

*Hemiaspis tunnecliffei* F. Chapman, Proc. Roy. Soc. Vic., n.s., 44 (1), p. 102, pl 14, figs 4, 5, 29th February, 1932.

M.U.G.D. No. 1201. HOLOTYPE, figured by Chapman, loc. cit., 1932, where the register number is erroneously stated to be 1801.

Upper Silurian (Melbournian).

"Road Cutting, Studley Park, Kew, Melbourne, Victoria" (Chapman, loc. cit., 1932). In the Register of Fossils in Melbourne University Geology Department, the locality is given as "Track to Pumping Station (? Monograptus bed), near Johnston Street Bridge, Studley Park, Victoria."

Presented by Master T. Tunnecliffe, jun., 8.7.31.

## PISCES.

### **Antiarchan fish**, ?genus.

Antiarchan, genus indet., E. S. Hills, Proc. Roy. Soc. Vic., n.s., 48 (2), p. 163, text-fig. 3, 1st June, 1936.

M.U.G.D. No. 1590. FIGURED PLASTER CAST, posterior median dorsal plate, figured by Hills, loc. cit., 1936.

Middle Devonian.

Gilberton District, Queensland.

Presented (plaster cast) by Dr. F. W. Whitehouse, 1935, the original being in his possession.

### **Bothriolepis gippslandiensis** Hills, 1929.

*Bothriolepis gippslandiensis* E. S. Hills, Proc. Roy. Soc. Vic., n.s., 41 (2), p. 195, text fig. 2, No. 4 (p. 196), pl. 18, fig. 8, April, 1929. E. S. Hills, Geol Mag., 68 (5), p. 214, text figs. 5 (p 215), 6, Nos. 1-3 (p. 218), 7, Nos. 1, 3 (p. 220), May, 1931.

M.U.G.D. No. 776. HOLOTYPE, specimen C.B., median occipital plate, figured by Hills, loc. cit., pl. 18, fig. 8, 1929.

M.U.G.D. No. 789. PARATYPE, specimen C.L., external marginal plate, figured by Hills, loc. cit., text fig. 2, No. 6, 1929.

M.U G.D. No 1882. Hypotype, specimen T22*a*, anterior ventro-lateral plate, figured by Hills, loc. cit., pl. 11, fig. 5, 1931.

M.U.G.D No. 1883. Counterpart of Hypotype No. 1882.

M.U.G D. No. 1884. Hypotype, specimen T10*b*, pectoral appendage, figured by Hills, loc. cit, pl. 11, fig. 2, 1931.

M.U.G.D. No. 1885. Counterpart of Hypotype No. 1884.

M.U.G.D. No. 1886. Hypotype, specimen T28*a*, left posterior dorso-lateral plate, figured by Hills, loc. cit., pl. 11, fig. 3, 1931.

M.U.G D. No. 1887. Hypotype, specimen T37*a*, anterior median dorsal plate, figured by Hills, loc. cit., pl. 11, fig. 6, 1931.

M.U.G D. No. 1888. Hypotype, specimen T38*a*, anterior median dorsal plate, figured by Hills, loc. cit., pl. 11, fig. 4, 1931.

M.U.G.D. No. 1889. Counterpart of Hypotype No. 1888.

M.U G.D No. 1890 Counterpart of Hypotype No. 1889.

M.U.G.D. No 1891. Hypotype, specimen T36*a*, anterior median dorsal plate, figured (as median section) by Hills, loc. cit., text fig. 7, No. 1, 1931.

M.U.G.D. No. 1892. Counterpart of Hypotype No. 1887.

M.U.G.D. No. 1893. Plaster Cast of counterpart No. 1892.

M.U.G.D. No 1894. Hypotype, specimen T8*a*. median occipital plate, and counterpart (No. 1895), specimen T8*b*, described by Hills, loc. cit., pp. 217-8, 1931.

M.U.G.D. No. 1896. Hypotype, specimen 1A, premedian plate, upper surface, and counterpart (No. 1897), specimen 1B, lower surface, described by Hills, loc. cit., pp. 218-9, 1931.

M.U.G.D. No. 1898. Hypotype, incomplete posterior median dorsal plate, described by Hills, loc. cit., p. 221, 1931, and anterior median dorsal plate.

M.U.G.D. No. 1899. Hypotype, specimen T27*a*, posterior dorso-lateral plate, upper surface, and counterpart (No. 1900), specimen T 27*b*, lower surface, described by Hills, loc. cit., p. 221, 1931.

M.U.G.D. No. 1901. Hypotype, specimen T34*a*, anterior dorso-lateral plate, upper surface, and counterpart (No. 1902), specimen T34*b*, lower surface, described by Hills, loc. cit., p. 221, 1931.

M.U.G.D. No. 1903. Hypotype, specimen T34*c*, posterior ventro-lateral plate, upper surface, described by Hills, loc. cit., p. 221, 1931.

M.U.G.D. No. 1904. Hypotype, specimen T26*a*, median ventral plate, upper surface, and counterpart (No. 1905), specimen T26*b*, lower surface, described by Hills, loc. cit., p. 221, 1931.

M.U.G.D. No. 1906. Hypotype, specimen T16*a*, brachial plates, upper surface, and counterpart (No. 1907), specimen T16*b*, lower surface, described by Hills, loc. cit., pp. 221-2, 1931.

Upper Devonian.

Blue Hills, near Taggerty, Victoria.

Coll. and pres. E. S. Hills, 20.2.29.

## **Bothriolepis** sp.

*Bothriolepis* sp., E. S. Hills, Proc. Roy. Soc. Vic., n s, 48 (2), p. 165, text fig. 5, pl. 12 (p. 170), fig. 3, June, 1936.

M U.G.D. No. 1588 FIGURED SPECIMEN, right pectoral fin, figured by Hills, loc. cit., pl. 12, fig. 3, 1936.

M.U G.D. No. 1589. FIGURED SPECIMEN, ventro-lateral plate, figured by Hills, loc. cit., text fig. 5, 1936.

Upper Devonian.

Allotment 75A, Parish of Loyola, South Blue Range, near Mansfield, Victoria.

Coll. H. B. Hauser, 1933.

## **Diodon connewarrensis** Chapman and Pritchard, 1907.

*Diodon connewarrensis* F Chapman and G. B. Pritchard, Proc. Roy Soc Vic., n.s., 20 (1), p. 69, pl 8, figs. 8-10, August, 1907. F. Chapman and F. A. Cudmore, *ibid.*, 36 (2), p. 147, 1924.

M.U.G.D. No. 1838. HOLOTYPE, spine, figured by Chapman and Pritchard, loc. cit., 1907.

Miocene (Balcombian).

Point Campbell clays, Lake Connewarre, near Geelong, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10.39.

## **Diodon formosus** Chapman and Pritchard, 1907.

*Diodon formosus* F. Chapman and G. B. Pritchard, Proc Roy Soc Vic, n s., 20 (1), p. 66, pl. 6, figs. 1-3; pl. 7; pl. 8, figs. 1-7, August, 1907 F. Chapman, Australasian Fossils, pp. 270, 271, fig. 131*f*, 1914. F. Chapman and F. A. Cudmore, Proc. Roy. Soc. Vic., n s, 36 (2), p. 146, 1922.

M.U.G.D. No. 1837. PARATYPE, jaw of young example, figured by Chapman and Pritchard, loc. cit., pl. 8, fig. 4, 1907.

Upper Miocene (Cheltenhamian) [Beaumaris] or Lower Pliocene (Kalimnan) [Grange Burn].

Beaumaris, Port Phillip, Victoria (*fide* paper label with specimen, in Chapman's pencilled writing). Explanation to plate states fig. 4 (of which this is undoubtedly the original) to be from Grange Burn. The black colour of the specimen favours Grange Burn but is not decisive.

Purchased from Dr. G. B. Pritchard, 11.10.39.

## **Dipterus microsoma** (Hills, 1929).

See *Eoctenodus microsoma* Hills, 1929.

## **Edaphodon sweeti** Chapman and Pritchard, 1907.

*Edaphodon sweeti* F. Chapman and G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 20 (1), p. 61, pl. 5, figs. 4-6, August, 1907. F. Chapman and F. A. Cudmore, *ibid.*, 36 (2), p. 141, pl. 11, figs. 38. 39, 1924.

M.U.G.D. No 1834. SYNTYPE, left palatine tooth, figured by Chapman and Pritchard, loc. cit., fig. 6, 1907.

Upper Miocene (Cheltenhamian).

Beaumaris, Port Phillip, Victoria. Though not so labelled, it is almost certainly from the nodule bed at the base of the cliffs.

Purchased from Dr. G. B. Pritchard, 11.10.39.

M.U G.D. No. 1835. Syntype, right vomerine tooth, figured by Chapman and Pritchard, loc. cit., fig. 5, 1907.

Lower Pliocene (Kalimnan).

Grange Burn, near Hamilton, Victoria.

Purchased from Dr. G. B. Pritchard, 11.10 39.

**Eoctenodus microsoma** Hills, 1929:—**Dipterus microsoma** (Hills, 1929).

*Eoctenodus microsoma* E S. Hills, Proc. Roy. Soc. Vic, n s., 41 (2), p. 193. text fig. 2, Nos. 1-3, 5, 6 (p. 196), pl. 18, figs 2-7, April, 1929.
*Dipterus microsoma* (Hills, 1929). E. S. Hills, Geol Mag., 68 (5), p 222, May, 1931.

M.U.G.D. No. 773. Holotype, specimen JFA, parasphenoid, figured by Hills, loc. cit., text fig. 2, No. 5, pl. 18, fig. 5, 1929. Associated is a scale, also figured on pl. 18, fig. 5.

M U.G.D. No. 770. Paratype, specimen C. XVII. *a*, left dentary of young, figured by Hills, loc. cit., pl. 18, fig. 2, 1929.

M.U.G.D. No. 771. Paratype, scale, figured by Hills, loc. cit, pl. 18, fig. 3, 1929.

M U.G.D. No. 772. Paratype, specimen C. XVIII. *a*, left cleithrum, figured by Hills, loc. cit., text fig. 2, No. 6, pl. 18, fig. 4, 1929.

M.U.G.D. No. 774. Paratype, specimen JC, scale, figured by Hills, loc cit., pl. 18, fig. 6, 1929.

M.U.G.D. No. 775. Paratype, specimen JA, left dentary, figured by Hills, loc cit., text fig. 2, No. 1, pl. 18, fig. 7, 1929.

M.U.G.D No. 780. Paratype, counterpart of paratype No. 771.

M.U.G.D. No. 781. Paratype, specimen C. XVIII. *b*, counterpart of paratype No. 772.

M.U.G.D. No. 782. Paratype, specimen JF, counterpart of holotype No. 773.

M.U.G.D. No. 783. Paratype, specimen C iv, counterpart of paratype No. 774.

M.U.G.D. No. 784. Paratype, specimen JB1, left dentary.

M.U.G D. No. 785. Paratype, specimen C.MO1, median occipital, figured by Hills, loc. cit., text fig. 2, No. 2, 1929.

M.U.G.D. No. 786. Paratype, specimen C.MO2, counterpart of paratype No. 785.

M.U.G.D. No. 787. Paratype, specimen JE3, counterpart of paratype No. 784.

M.U.G.D. No. 788. Paratype, specimen C.C., clavicle, figured by Hills, loc. cit., text fig. 2, No. 3, 1929.

M.U.G.D. No. 1736. Paratype, specimen C xv, scales, fin-bones and rays, described by Hills, loc. cit., p. 195, 1929.

Upper Devonian.

Blue Hills, near Taggerty, Victoria.

Coll and pres. E. S. Hills, 20.2.29.

**Labrodon depressus** Chapman and Pritchard, 1907:—
**Nummopalatus depressus** (Chapman and Pritchard, 1907.)

*Trygon ensifer* J. W. Davis (*pars*), Trans. Roy. Dubl. Soc. [2] 4, p. 37, pl. 6, figs 13, 13*a*, 13*b*, 1888.

*Labrodon depressus* F. Chapman and G. B. Pritchard, Proc. Roy. Soc. Vic., n.s., 20 (1), p. 66, pl. 5, figs. 8, 9, August, 1907. F Chapman, N Z. Geol. Surv. Pal. Bull. 7, p 27, pl 6, figs. 13, 13*a*, 13*b*, 1918

*Nummopalatus depressus* Chapman and Pritchard sp.: F. Chapman and F. A. Cudmore, Proc Roy. Soc. Vic., n.s., 36 (2), p 143, pl. 11, fig 43, 1924.

M.U.G.D. No. 1836. HOLOTYPE, pharyngeal, figured by Chapman and Pritchard, loc. cit., 1907.

Upper Miocene (Cheltenhamian).

Beaumaris, Port Phillip, Victoria. Though not so stated, it is almost certainly from the nodule bed at this locality.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Myliobatis moorabbinensis** Chapman and Pritchard, 1907.

*Myliobatis moorabbinensis* F. Chapman and G. B. Pritchard, Proc Roy Soc. Vic., n s., 20 (1), p. 60, pl. 5, figs. 1-3, August, 1907. F. Chapman and F. A. Cudmore, *ibid.*, 36 (2), p. 138, 1924. Not "*Myliobatis moorabbinensis* Chapman and Pritchard": F Chapman and C. J Gabriel, *ibid.*, 27 (1), p. 57, pl. 10, fig. 57, 1914. F. Chapman, Rec. Geol. Surv. Vic., 3 (4), pp. 339, 353, 355, pl. 76, fig 57, 1916. F. Chapman, Proc. Roy Soc. Vic., n.s., 29 (2), p. 139, pl. 9, fig. 8 (=*Myliobatis affinis* F. Chapman and F. A. Cudmore, loc. cit., p. 139, pl. 10, fig. 36, 1924).

M.U.G.D. No. 1833. PARATYPE, figured by Chapman and Pritchard, loc cit., fig. 3, 1907.

Upper Miocene (Cheltenhamian).

Beaumaris, Port Phillip, Victoria. Though not so labelled, it is almost certainly from the nodule bed at the base of the cliffs.

Purchased from Dr. G. B. Pritchard, 11.10.39.

**Nummopalatus depressus** (Chapman and Pritchard, 1907).

See *Labrodon depressus*, Chapman and Pritchard, 1907.

**Phyllolepis** sp.

*Holonema* cf. *rugosum* Newberry, 1889 [recte (Claypole, 1886)]: E. S. Hills, Proc. Roy. Soc. Vic., n.s., 41 (2), p. 197, April, 1929. Not *Pterichthys* (?) *rugosus* E. W Claypole, Proc. Amer. Phil. Soc., 20 p. 666, with fig. 1883 = *Holonema rugosum* J. S. Newberry, Palaeozoic Fishes N. America, p. 92, 1889.

Phyllolepid plates: E. S. Hills, Geol. Mag., 68 (5), p. 212, text figs. 2 (p. 212), 3 (p. 213), May, 1931.

*Phyllolepis* sp.: E. S. Hills, Proc. Roy. Soc. Vic., n.s., 48 (2), p. 164, text fig. 4, pl. 12 (p. 170), figs. 1, 2, June, 1936.

M U.G.D. No. 790. FIGURED SPECIMEN C.H., lateral plate, described by Hills, loc. cit., 1929, and figured, pl. 12, fig. 2, 1936.

M.U G.D. No. 791. FIGURED SPECIMEN, plate, Type 1, figured by Hills, loc. cit, text fig. 2, No. 1, 1931.

M.U.G.D. No. 1878. FIGURED SPECIMEN, T.3*a* P, plate, Type 1, figured by Hills, loc. cit., text fig. 2, No. 2, 1931.

M.U.G.D. No. 1879. COUNTERPART OF FIGURED SPECIMEN No. 1878.

M.U.G.D. No. 1880. FIGURED SPECIMEN, T.1*a* P, plate, Type 2, figured by Hills, loc. cit., text fig. 2, No. 3, 1931.

Upper Devonian.

Blue Hills, near Taggerty, Victoria.

Coll. and pres. E. S. Hills, 20.2.29.

M.U.G.D. No. 1587. FIGURED SPECIMEN, ventral plate, figured by Hills, loc. cit., text fig. 4, 1936.

Upper Devonian.

Allotment 75A, Parish of Loyola, South Blue Range, near Mansfield, Victoria.

Coll. H. B. Hauser, 1933.

## **Spaniodon elongatus** Pictet, 1850.

*Spaniodon elongatus* F J. Pictet, Poiss Foss Mt. Liban, p. 35, pl. 6, figs. 1, 2, 1850 F. J Pictet et A Humbert, Nouv. Rech. Poiss Foss. Mt. Liban, p. 85, pl. 12, figs 1, 2, 1866. J. W. Davis, Sci. Trans. Roy. Dublin Soc., [2] 3, p. 588, April, 1887. A. S. Woodward, Cat. Foss. Fishes Brit. Mus., pt. 4, p 51, pl. 7, fig 3, 1901. E S. Hills, Proc. Roy. Soc. Vic., n.s., 48 (1), p. 50, pl. 2, December, 1935.

M.U.G.D. No 833. HYPOTYPE, figured by Hills, loc. cit., 1935.

Upper Cretaceous.

Mount Lebanon, Syria.

Purchased from T. Worcester.

# CETACEA.

## **Mammalodon colliveri** Pritchard, 1939.

*Mammalodon colliveri* G. B. Pritchard, Vic Naturalist, 55 (9), p. 157, text figs. 1 (p. 152), 2 (p. 154), 3 (p. 156), 4, 5 (p. 157), 4th January, 1939

M U.G.D. No. 1874. HOLOTYPE, skull and lower jaw, figured by Pritchard, loc. cit., 1939.

Miocene (Janjukian).

Lower beds, Bird Rock cliffs, near Spring Creek, Torquay, Victoria "About 12 ft. above the level of the beach . . . barely a hundred yards around [S.W. of] the Bird Rock corner . . . ." (Pritchard, loc. cit., p. 151, 1939). It is from about a foot above the Spring Creek ledge at its extreme S.W. margin (F. S. Colliver, personal communication, 23 10.44) and is thus from within the Glycymeris beds.

Pres. F. S. Colliver, 19.10.39.

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Sayce, E. L., B.Sc., A.Inst.P., Research Laboratories, Maribyrnong, W.3 1924
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